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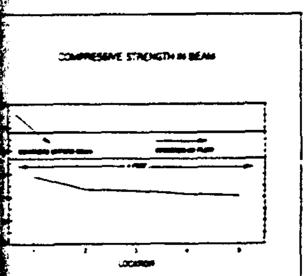

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REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-34

LABORATORY EVALUATION OF CONCRETE MIXTURES AND TECHNIQUES FOR UNDERWATER REPAIRS

by

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HY	Hydraulics	OM	Operations Management
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COVER PHOTOS:

TOP — Inclined tremie used to fill box, trial 6

BOTTOM — Concrete density and compressive strength in beam, trial 4

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Concrete mixtures were placed underwater using six placement techniques to (a) examine the cohesive and flow parameters of selected concrete mixtures under different placement situations, (b) estimate those parameters necessary for successful underwater placement, (c) examine the quality of bonding of the repair concrete to the existing concrete, and (d) examine the effect of underwater placement upon the abrasion resistance of the concrete.

A washout test was used to determine the relative amount of cement paste lost when the concrete is exposed to a large volume of water. The two-point workability test was used to evaluate the relative workability properties of the concretes. The slump, tremie flow, and air content were also measured. The test method for abrasion-erosion resistance of concrete (underwater method) was used to determine the abrasion-erosion resistance of each concrete. A point-load tensile test was used to determine the bond strength of the repair concrete to the existing concrete.

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The results indicated that cohesive, flowable, abrasion-resistant concrete that will bond well to existing concrete can be placed underwater by available methods if proper materials are used and precautions are taken.

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit No. 32305, "Techniques for Underwater Concrete Repairs," for which Mr. Kenneth L. Saucier, Concrete Technology Division (CTD), Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), is the Principal Investigator. This work unit is part of the Concrete and Steel Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The REMR Overview Committee at HQUSACE consists of James E. Crews (CECW-OM) and Dr. Tony C. Liu (CECW-EG). Dr. Liu was also the Technical Monitor.

The investigation was performed at WES under the general supervision of Messrs. Bryant Mather, Chief, SL, and John M. Scanlon, former Chief, CTD. Direct supervision was provided by Mr. Saucier, Chief, CTD. The laboratory work was directed by Mr. Saucier and Mr. Billy D. Neeley, CTD, with assistance from Messrs. Mike Lloyd, Tom Lee, Julies Mason, Percy Collins, Frank Dorsey, Eugene James, Toy Poole, Melvin Sykes, and Ms. Carolyn Corbett, all of CTD. Mr. Neeley, Mr. Saucier, and Mr. Henry T. Thornton, Jr., formerly of CTD, prepared this report. Program Manager for REMR is Mr. William F. McCleese, CTD, and the Problem Area Leader is Mr. James E. McDonald, CTD. This report was published by the Information Technology Laboratory, WES.

Commander and Director of WES is COL Larry B. Fulton, EN. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Concluded)

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.07645549	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
fluid ounces	0.00002957353	cubic metres
fluid ounces per cubic yard	0.038680715	litres per cubic metre
inches	25.4	millimetres
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre

LABORATORY EVALUATION OF CONCRETE MIXTURES AND TECHNIQUES FOR UNDERWATER REPAIRS

PART I: INTRODUCTION

Background

1. Many hydraulic structures in use in the United States today are deteriorating as a result of environmental effects and abrasion-erosion damage to the concrete. Dewatering of hydraulic structures for repair is usually difficult and expensive, costing as much as $1,000,000 and averaging approximately 40 percent of the total cost of repairing erosion damage in stilling basins (McDonald 1980). A state-of-the-art report on techniques for the underwater repair of concrete structures subjected to abrasion-erosion (Gerwick 1988) suggested that pumped concrete offered excellent potential for underwater placement, particularly when used with newly developed pneumatic control valves and admixtures.

2. Saucier and Neeley (1987), Neeley (1988 and 1989) addressed the use of antiwashout admixtures (AWA) in concrete for underwater repair of stilling basins. The program consisted of a laboratory evaluation of five selected AWA's. The results of the study indicated that the AWA's did impart a significant amount of cohesiveness to typical underwater concrete mixtures. Indeed, an excessive amount of AWA rendered the concrete cohesive to the degree of being unworkable. The key then becomes the successful optimization of AWA dosage in conjunction with water-reducing admixtures (WRA) or high-range water-reducing admixtures (HRWRA) used to increase slump. Previous work by Holland (1983) indicated that silica fume in concrete substantially increased resistance to abrasion-erosion effects. Silica fume added to the mixtures also increased the cohesiveness of the concrete and provided another variable to the optimization process. These are important parameters for successful underwater placement, since the concrete must be cohesive, yet flowable. In fact, the parameters required for successful placement could be different for different placement techniques.

Objectives

3. The objectives of this study were (a) to examine the cohesive and flowable parameters of selected concrete mixtures under different placement situations, (b) to estimate those parameters necessary for successful underwater placement, (c) to examine the quality of bonding of the repair concrete to the existing concrete, and (d) to examine the effect of underwater placement upon the abrasion resistance of the concretes.

PART II: EXPERIMENTAL PROGRAM

4. This chapter summarizes the experimental part of the investigation involving 18 trial placements using 14 concrete mixtures and 6 placement techniques. The concretes were placed into as many as five containment situations. The concrete mixtures, test procedures, placement techniques, and concrete containment are described below. A summary of the program is shown in Table 1.

Concrete Mixtures

5. The concrete mixtures chosen for use in trials 1 through 8 of this investigation had demonstrated a high degree of workability, good abrasion-erosion resistance, and good washout resistance in previous work (Neeley 1988). The concretes differed only in the amount and type of AWA. Unless indicated otherwise, all mixtures contained silica fume, HRWRA, AWA, and 1-in. nominal maximum size natural gravel. The concrete mixture used in trial 9 was an air-entrained mixture suitable for traditional tremie placements. This mixture did not contain silica fume nor AWA. The concrete mixture used in trial 10 was the same as the mixture used in trial 1; it contained no AWA. The concrete mixture used in trial 11 had a high cementitious material content (1,000 lb/cu yd*) and a low water-cement ratio (w/c) (0.28). During the course of the investigation, the US Army Engineer District (USAED), Rock Island, requested assistance in making an underwater repair to an eroded end-sill. Guidelines were provided to field personnel for proportioning a concrete mixture to be used in making an underwater repair. The concretes used in trials 12 and 13 were within the guidelines provided to the Rock Island District. Materials on hand similar to those proposed for use at the project site were used in the two concretes, 3/4-in. nominal maximum size crushed limestone, WRA, and AWA. The concrete used in trial 14 contained 3/8-in. nominal maximum size natural gravel, fly ash, HRWRA, and AWA. The concrete used in trial 15 contained fly ash and AWA. Silica fume was not used in trials 12 through 18. Pertinent information for all concrete mixture proportions is given in Table 2.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 5.

Test Procedures

6. The slump (American Society for Testing and Materials (ASTM) C 143-78 (ASTM 1987)), air content (ASTM C 231-82 (ASTM 1987)), tremie flow (CRD-C 32-84 (US Army Engineer Waterways Experiment Station (USAEWES) 1949)), washout (Neeley 1988), and two-point workability (Tattersall and Banfill 1983) were used to qualify and quantify the various mixtures. Three 4-in.-diam by 8-in.- high cylindrical specimens were cast according to ASTM C 192-81 (ASTM 1987). These specimens were tested in compression according to ASTM C 39-84 (ASTM 1987) at age 28 days. Some specimens were not tested until a later age due to a scheduling error. In most trials, abrasion-erosion specimens were cast both above water and underwater. These abrasion-erosion specimens were tested according to CRD-C 63-80 (USAEWES 1949) beginning at age 28 days. The volume loss per unit surface area was measured rather than the mass loss as prescribed in CRD-C 63-80, to compare results from specimens less than 4-in. high to standard size specimens. After the concrete hardened in the trial placements, the forms were stripped and 4-in.-diam cores were taken through the new concrete into the old abrasion specimens. The cores were tested for bond strength of the joint and for tensile strength of the old and new concrete by use of a point-load tensile test as shown in Figure 1 (Reichmuth 1963 and Robins 1980). Cores were also taken and tested for density and compressive strength according to ASTM C 42-84 (ASTM 1987).

Placement Techniques

7. The concretes were placed underwater by six different methods. Method 1 consisted of free-fall of concrete through up to 3 ft of water (no protection from dilution) as it discharged from a transit mixer chute. Method 2 consisted of pumping the concrete to the point of underwater placement (complete protection, but no tremie seal maintained). Method 3 involved the use of a 1/2-cu-yd bottom dumping concrete bucket with a chute attached below the mouth of the bucket supporting the concrete to the point of final disposition (partial protection). Method 4 involved the use of an inclined chute that supported the concrete to the point of final disposition and partially protected the concrete from washout. Method 5 consisted of lowering a 1/2-cu-yd bottom dumping concrete bucket into the water to a point 1 ft above

the point of disposition and allowing the concrete to free-fall through 1 ft of water. Method 6 consisted of free-fall of concrete through up to 3 ft of water (no protection from dilution) as it discharged from a skip bucket with a narrow chute.

Concrete Containment

8. The concretes were placed into as many as five different containers. Container 1 was a 4-ft-diam by 4-ft-high steel cylindrical tank. Previously tested abrasion specimens were placed abraded side up in the bottom of the tank. Container 2 was an 8-in.-wide by 8-in.-deep by 4-ft-long steel beam mold. Container 3 was abrasion molds. Container 4 was a large plywood box, 4 ft wide, 4 ft long, and 16 in. deep. Previously tested abrasion specimens were placed abraded side up in the bottom of the box. Container 5 was a small plywood box, 3 ft square and 8 in. deep. Previously tested abrasion specimens and sections of 6-in.-square concrete beams were placed in the bottom of the box.

PART III: TEST RESULTS AND DISCUSSION

9. A description of each trial placement along with the results from tests on the fresh and hardened concrete are presented and discussed in this part. Tests on the fresh concrete for all trials include slump, air content, tremie flow, washout, and two-point workability. The concrete mixture proportions are given in Table 2. Tests on the hardened concrete include compressive strength and density of cores, abrasion resistance, and bond strength of the new concrete to old concrete.

Description of Concrete Placement

Trial 1

10. Three cubic yards of concrete mixture 12CON was batched in an eight-cubic-yard transit mixer. The concrete was discharged directly into the steel tank, the beam mold, and the abrasion molds. In the steel cylindrical tank, the concrete was in a free-fall through 3 ft of water and resulted in complete disaggregation of the fresh concrete (Figures 2 and 3). Approximately 4 in. of weak mortar settled on top of the concrete (Figure 4). The porous friable concrete after hardening is shown in Figure 5. The mixture was discharged into one end of the beam mold and allowed to flow to the other end until the beam was filled (Figure 6). In Figure 7, the concrete beam after hardening is shown. The concrete fell through 1 ft of water to fill four abrasion molds. The tops of two of these specimens were screeded underwater; two were left untouched. Two specimens were also cast in air.

Trial 2

11. Three cubic yards of concrete mixture 87 was batched in an eight-cubic-yard transit mixer. The AWA was added to the concrete after approximately 15 min of mixing and hauling time. The concrete was discharged directly into the tank, the beam mold, and the abrasion molds in the same manner as in trial 1. In Figures 8 and 9, the concrete is discharged into the steel tank. Although there was some loss of fines, the hardened concrete was a solid mass (Figure 10). Concrete is discharged into the beam mold and is shown in Figure 11; the hardened concrete is shown in Figure 12. The hardened abrasion specimens that were cast underwater are shown in Figure 13.

Trial 3

12. Four cubic yards of concrete mixture 87 was batched in an eight-cubic-yard transit mixer. The AWA was added to the mixer as the other materials were being loaded. The concrete was deposited into the tank, the beam mold, the abrasion molds, and the large box with boom pump having a 5-in. line. The pump was rated at 109 cu yd/hr with a maximum pressure of 4,500 psi. The mixture was pumped approximately 25 ft with a pressure of 300 to 400 psi. The end of the pump line was placed near the bottom of each container and was moved horizontally as the concrete was pumped into the tank and the large box. No attempt was made to maintain a seal, yet only a small loss of fines was observed in the water (Figure 14). The concrete was stiff and had to be moved underwater by hand. The screeded surface of the box after the concrete had hardened is shown in Figure 15. The end of the pump line was placed at one end of the beam mold, allowing the concrete to flow to the other end. The hardened concrete beam is shown in Figure 16. Two abrasion molds were filled underwater; the tops were not screeded.

Trial 4

13. Four cubic yards of concrete mixture 78 was batched in an eight-cubic-yard transit mixer as described in trial 3. The concrete was deposited into the tank, the beam mold, the abrasion molds, and the large box by a trailer pump with a 5-in. line. The pump was rated at 120 cu yd/hr with a maximum pressure of 4,500 psi. The concrete was pumped approximately 25 ft with a pressure of 300 to 400 psi into each container as described in trial 3 (Figures 17 through 19). The concrete was more fluid in this than in trial 3 and moved well underwater. With only a small loss of fines observed in the water, the concrete placement could be seen through 4 ft of water (Figure 20). Figure 21 shows the two hardened abrasion specimens.

Trial 5

14. Four cubic yards of concrete mixture 78 was batched in an eight-cubic-yard transit mixer as described in trial 3. A 1/2-cu-yd bottom dumping concrete bucket with a chute attached below the mouth of the bucket was filled with the mixture and positioned so that the end of the chute was below the waterline. The stiff mixture was allowed to free-fall approximately 1 ft into the large box but would not readily move down the chute. A pencil vibrator was inserted into the concrete to aid movement down the chute. Only a small loss of fines was observed (Figure 22). The concrete was redosed with WRA to

increase the workability. The beam mold and the abrasion molds were then filled directly from the discharge chute on the transit mixer, and the abrasion specimens were screeded underwater. Figures 23 and 24 show the hardened specimens from each container.

Trial 6

15. Three cubic yards of concrete mixture 87 was batched in an eight-cubic-yard transit mixer as described in trial 3. The inclined tremie was used to fill the large box (Figures 25 and 26). The open top of the tremie allowed exposure to the water on the top surface for a distance of approximately 7 ft as the concrete moved down the slope. The concrete flowed smoothly down the tremie without a significant loss of fines. The mixture also flowed well underwater (approximately 3 ft) and completely filled the large box. The concrete was pumped into a second box, and again flowed freely underwater and completely filled the large box without a significant loss of fines. The top surface of the concrete was screeded in both boxes to level the approximate 15-deg slope of the completed placements. The mixture was pumped into the beam and the abrasion molds (Figure 27). Figure 28 shows the hardened concrete in the box that was placed with the pump.

Trial 7

16. One-half cubic yard of concrete mixture 79 was mixed in a sixteen-cubic-foot revolving-drum laboratory mixer. The concrete was placed in the large box by the inclined tremie but would not flow down the tremie at a 35-deg angle. A pencil vibrator was inserted at the mouth of the tremie to move the concrete. The vibrator was also inserted into the box at several points and apparently caused the concrete to consolidate satisfactorily. There was no significant loss of fines, even with vibration, and the water was only slightly cloudy after the placement. Two abrasion molds were filled and screeded underwater.

Trial 8

17. One-half cubic yard of concrete mixture 80 was mixed as described in trial 7. The inclined tremie again was used to fill the large box. The concrete flowed down the tremie smoothly at a 25-deg angle without a significant loss of fines and with less clouding of the water than in trial 6. The concrete flowed to most areas of the box, though not as evenly as in trial 6. The surface of the concrete was screeded underwater, and two abrasion molds were filled and screeded underwater.

Trial 9

18. One-half cubic yard of concrete mixture 101 was mixed as described in trial 7. This concrete was air-entrained and typical of what might be used in a traditional tremie placement. The inclined tremie was used to fill the large box. The concrete flowed down the tremie smoothly at a 20-deg angle. There was a considerable loss of fines, clouding of the water was significant (Figure 29), and froth collected on top of the water after placement (Figure 30). Two abrasion molds were filled and screeded underwater (Figure 31).

Trial 10

19. One-half cubic yard of concrete mixture 12CON was mixed as described in trial 7. The inclined tremie was used to fill the large box. The concrete flowed smoothly down the tremie but did not flow underwater to fill the box. There was not a significant loss of fines, and the concrete placement could be vaguely seen through 4 ft of water. Two abrasion molds were filled and screeded underwater.

Trial 11

20. One-half cubic yard of concrete mixture 102 was mixed as described in trial 7. This concrete had a high cementitious material content (1,000 lb/cu yd) and a low w/c (0.28). The inclined tremie was used to fill the large box with almost no loss of fines. The concrete could be seen clearly through 4 ft of water (Figure 32). The concrete flowed satisfactorily underwater to fill the box (Figure 33). Two abrasion molds were filled and screeded underwater (Figure 34).

Trial 12

21. One-half cubic yard of concrete mixture 103 was mixed as described in trial 7. The concrete was proportioned to meet guidelines provided to the Rock Island District for making an underwater repair. Materials on hand, similar to those proposed for use at the project site, were used in the concrete. The mixture was held in a bottom dumping concrete bucket and lowered into the water to a level of approximately 1 ft above the large box. The concrete was allowed to free-fall out of the bucket through 1 ft of water. The concrete flowed freely from the bucket and filled the box, but was not self-leveling (Figure 35). There was some loss of fines, and the water was moderately cloudy after placement.

Trial 13

22. One-half cubic yard of concrete mixture 104 was mixed and placed as described in trial 12. However, the HRWRA used in this trial was a naphthalene sulfonate. A concrete having improved washout resistance was not identified in previous work by Neeley (1988) when this HRWRA was used. The concrete flowed out of the bucket so rapidly that it sloshed over the sides of the large box. There was a significant loss of fines, the water was muddy after the placement (Figure 36), and froth collected on the surface of the water (Figure 37). The concrete was almost self-leveling (Figure 38).

Trial 14

23. One-half cubic yard of concrete mixture 105, a pea-gravel concrete, was mixed as described in trial 7. The inclined tremie was used to fill the large box. The concrete flowed smoothly down the tremie with little loss of fines (Figure 39). The placement could be vaguely seen through 4 ft of water. The mixture was almost self-leveling. The hardened concrete is shown in Figure 40.

Trial 15

24. One-half cubic yard of concrete mixture 106 was mixed as described in trial 7. The inclined tremie was used to fill the large box. The concrete flowed easily down the tremie, and some loss of fines was evident, rendering the placement not visible through 4 ft of water. The concrete flowed evenly underwater and was almost self-leveling (Figure 41).

Trial 16

25. Three cubic feet of concrete mixture 107 was mixed in a nine-cubic-foot rocking-tilting laboratory mixer. The small box containing old concrete specimens was placed in the steel cylindrical tank filled with water (Figure 42). The concrete was discharged from a skip bucket with a narrow chute and allowed to free-fall through 3 ft of water. The mixture was very sticky, yet self-leveling immediately after pouring. The water was cloudy after the placement, but no foam formed on the surface of the water. The concrete required 10 days to attain a final set. All areas of the box were filled as illustrated by the hardened concrete (Figure 43).

Trial 17

26. Three cubic feet of concrete mixture 108 was mixed and placed as described in trial 16 (Figure 44). The concrete was sticky, yet self-leveling immediately after pouring. The coarse aggregate tended to settle to the

bottom, indicating a need for improvement in proportioning. Even though this concrete was somewhat more flowable than that used in trial 16, the washout appeared to be similar. The water was cloudy after the placement, but no foam was on the surface of the water (Figure 45). The concrete filled all areas of the box, but the cement matrix was not as dense as that in trial 16.

Trial 18

27. Three cubic feet of concrete mixture 109 was mixed and placed as described in trial 16. The concrete was very sticky and did not self-level immediately; however, it did self-level after a short period of time (Figures 46 and 47). The concrete was so sticky that it discharged from the skip bucket in slugs rather than in a continuous stream. Even so, there was very little washout (Figure 48). The water was slightly cloudy after the placement, but no foam was on the surface of the water (Figures 49 and 50). The concrete filled all areas of the box; it was homogeneous and dense (Figure 51). It was a better quality concrete than that of trials 16 and 17. The concrete required 2 days to reach a final set.

Tests on Fresh Concrete

Slump, tremie flow, and two-point workability

28. The slump, tremie flow, and two-point workability tests indicated that the concrete mixtures in trials 3, 5, and 7 did not have a high degree of workability. Problems were encountered in each of these trials due to concrete workability. While none of the three tests gave conclusive evidence describing the degree of workability, in each trial at least one of the tests indicated that problems with workability could exist.

29. These tests indicated that the concretes in all other trials did have good workability. No problems were encountered during these placements as the result of poor workability. The concretes in trials 16, 17, and 18 were self-leveling. The concretes in trials 1, 6, 9, 11, 13, 14, and 15 were almost self-leveling, while the concretes in trials 2, 4, 8, 10, and 12 were not self-leveling. As stated above, none of the three tests gave conclusive evidence describing the degree of workability; however, some trends were observed. They are:

a. The maximum tremie flow for the poor workability concrete was 13-1/4 in.; the minimum tremie flow for the self-leveling concrete was 16 in.

b. The minimum value "g" for the poor workability concrete was 3.56.

c. The maximum value "g" for the self-leveling concrete was 2.59; the minimum slump for the self-leveling concrete was 7-3/4 in.

Washout

30. The washout test indicated that the concretes in trials 1, 8, and 13 (Figure 52) were not cohesive enough to prevent a significant amount of the cement paste from washing out when exposed to a large amount of water. The percentages of cement paste lost in the tests were 6.0, 9.8, and 10.2, respectively. There was a significant loss of fines during the concrete placement of each of these trials. The maximum percentage of cement paste lost in the tests of the remaining trials was 3.0. There was not a significant loss of fines in any of these trial placements. The washout test could not be run on the concretes used in trials 14, 15, 16, 17, and 18. These concretes were so fluid that the cement paste seeped through the holes in the basket continuously, thus making it impossible to determine how much of the weight loss was actually due to a washing out of the cement paste.

Air content

31. An air-detraining agent (D-Air) was used in most concretes to prevent high air contents. Only the concretes in trials 9, 13, and 15 had air contents greater than 2.8 percent. Those air contents were 6.6, 9.5, and 9.8 percent, respectively. An air-entraining agent (AEA) was used in the concrete for trial 9. The combination of naphthalene HRWRA and an AWA contributed to the high air content in the mixture used in trial 13, even though the air-detraining agent was used. The air detraining agent was not used in the concrete for trial 15. The concretes having high air contents appear to have less resistance to washout than the concretes having lower air contents. The results of all fresh concrete tests are given in Table 3.

Tests on Hardened Concrete

Compressive strength and density of cores

32. After the concrete hardened in the beam mold in trials 1 through 6,

the forms were stripped and cores were taken down the center line of the beam at approximately 8-in. intervals (Figure 53). These cores were weighed in air and water to measure density, and then tested for compressive strength. The results indicate that the density and compressive strength decreased as the concretes moved laterally underwater from the point of discharge. However, the losses were significantly reduced when the concretes were made more cohesive (more resistant to washout) by the addition of an AWA. Figures 54 through 59 show plots of the density and compressive strength for the cores in trials 1 through 6, respectively.

Abrasion-erosion

33. The abrasion specimens from trials 1 through 11 were tested for underwater abrasion. The specimens not screeded underwater were cut prior to installation in the abrasion apparatus to provide a smooth surface. The abrasion resistance of these specimens compared favorably to that of those cast in air. Those specimens that were screeded underwater sustained additional abrasion loss. This was to be expected as the screeded surface was observed to have some laitance that formed as the concrete hardened underwater. Once the layer of laitance was abraded, the rate of loss was comparable to the cut specimens. Figures 60 through 70 show plots of the abrasion loss and the rate of abrasion loss for trials 1 through 11, respectively. The average rate of abrasion loss is shown in Figure 71.

Bond strength

34. After the concrete had hardened in the placements containing the previously abraded abrasion specimens, the forms were stripped and cores were taken through the new concrete into the old abrasion-erosion specimens (Figures 72 and 73). The cores were tested for bond strength of the joint and for tensile strength of the old and new concrete by use of a point-load tensile test. The results indicated that a good bond could be obtained between old concrete and new concrete placed underwater. Most tests resulted in clean bond breaks with some bonding material adhering to both surfaces. The results of all tests on the hardened concretes are given in Table 4.

35. The data were evaluated using the Statistical Analysis System on the IBM 4331 computer at USAEWES. Fourteen points were in the data set. An analysis of variance and Duncan's multiple range test indicated that the bond strength was not significantly affected by silica fume nor AWA. A stepwise regression analysis indicated that the bond strength was not affected by air

content, g, h, nor washout at a 0.05 level of significance.

Discussion

36. The concretes used in trials 6, 11, 14, 16, and 18 are typical of mixtures that would have good workability, be self-leveling, have minimal washout, give good bond, and be easily placed by pump or tremie. Mixtures in trials 4 and 8 have similar qualities but were not self-leveling. Each of these mixtures would have good abrasion resistance if a hard aggregate, such as chert or granite, was used.

37. In trials 3, 5, and 7, concretes were used that would maximize washout resistance and bond but would have poor workability. These mixtures probably could not be placed by pump nor tremie. Also, if the concretes were placed by some methods, considerable effort would be required to consolidate the concrete.

38. Trials 9 and 13 are typical of concretes that would have good workability and be self-leveling but would have considerable washout. Therefore, only fair bond could be expected. These mixtures could be placed by pump or tremie, but conventional practice for placing concrete underwater should be observed. The concrete should not be allowed contact with water until in place.

PART IV: INSPECTION OF UNDERWATER CONCRETE REPAIR

Conditions of Repair

39. Accurate, efficient methods are needed to assess the extent of damage and the type of repair necessary. Care must be exercised to ensure that proper procedures and materials are used to achieve excellent adhesion to damaged areas and to develop durable surfaces that are properly oriented. In most cases, during the actual repair, only cursory observations concerning the degree of success of the placement will be possible. Therefore, systems and techniques for after-the-fact inspection and monitoring of repairs made underwater should to be explored. It is obvious that the type, size, location, and environmental conditions of the underwater repair will dictate the technique or system of inspection and monitoring best suited to provide data on the condition of the repair.

Environmental Concerns

40. Although portland-cement concretes have a long history of use in aquatic environments, reasonable caution should guide the preparation, repair, and cleanup phases of repair activities involving potentially hazardous and toxic chemical substances. This report describes the use of chemical admixtures that, if used improperly, may have adverse health and environmental effects. Manufacturer's directions and recommendations for the protection of occupational health and environmental quality should be carefully followed. Material Safety Data Sheets should be obtained from the manufacturers of such materials.

41. Increased suspended solids loading by washout of cement fines from the concrete may be of some concern in sensitive environmental habitats if the exposure concentrations are high and the pH of the water is increased significantly. A neutralizing agent may reduce the toxicity to freshwater aquatic animals. If used properly, AWA will reduce the amount of cement fines dispersed into the water.

Methods of Inspection

Visual

42. Visual inspection is usually the first technique considered for underwater inspection. It may be accomplished with or without a diver. In certain cases visual inspection can be done from above the water by using an underwater scope. For instance, in the case of the repair of erosion in the Chief Joseph Dam, engineers made underwater observations through the use of a 35-ft-long underwater scope equipped with a 6-in.-diam bottom glass and a high-power telescope (McDonald 1980). Visual inspection is quick, easy, and nondestructive. However, there are numerous limitations to this type of inspection technique resulting from the environment or the diver. Environmental limitations include: (a) silt, mud, debris, etc., which obscure the surface unless cleaned; (b) poor visibility; and (c) strong currents, which make it difficult for the diver to work. Diver-imposed limitations range from inadequate training as an inspector to reduced attention resulting from cold or reduced visibility in water. For instance, when turbidity is high, underwater visibility can be nonexistent, even if the diver carries artificial lights.

Tactile

43. When the repair is in turbid water severely limiting visibility, a diver may touch and feel to characterize the surface formed by repair. Divers are capable of conducting inspection using only tactile methods in zero visibility, yet it is difficult, if not impossible, to assess the value of this technique. The task is even more difficult in cold water or when there is a strong current.

44. Tactile inspection requires greater preparation than when working in clear water. Attention should be given to the following items:

- a. In-depth study of plans.
- b. Good communications between diver and surface.
- c. Recorder to document voice transmission.
- d. Determination of position and depth of diver.

Remotely operated vehicle

45. Underwater inspection may be done with a remotely operated vehicle (ROV). ROV's used for this type of inspection have video cameras and lights

installed and are controlled from the surface with little diver participation. They can range from a small, relatively inexpensive system to a highly capable but expensive system (Marine Technology Society 1984).

46. The advantage of using ROV systems is that they can compensate for the inherent limitations of diver systems underwater because they can have very deep operating depths, long operating duration, can repeatedly perform the same mission with no performance degradation, and can be operated in locations where the water currents and tidal conditions make use of divers unacceptable. Disadvantages of using ROV systems are:

a. ROV's are expensive and require expensive support regardless of the depth of operation the mission requires. Such support consists of power generators, display monitors, vehicle controllers, cables, and spare parts.

b. ROV's are usually less flexible and less reliable than divers.

c. ROV systems tend to have greater maintenance requirements than the diver system.

d. Video cameras installed on ROV's may distort angles and dimensions when they are not referenced.

However, ROV technology is constantly improving, and numerous vendors and consultants perform these services.

Echosounders (specifically fathometers)

47. Echosounders are usually effective in checking large, relatively deep scours in the streambed. It is conceivable that this instrument could be used to obtain general data on the success of underwater repair of a large, relatively deep scour in a horizontal or inclined concrete structure. The resolution (ability to distinguish one object from another) would not be accurate enough to map a surface within plus-or-minus a few inches, but accurate enough to make a comparison of the before and after repair conditions. When used very near to vertical structures, erroneous returns may occur.

Side-scan sonar

48. The side-scan sonar system is similar to the standard bottom-looking echosounder except that the signal from the transducer is directed laterally and produces two side-looking beams. The system consists of a pair of transducers mounted in an underwater housing or "fish" and a dual channel recorder connected to the "fish" by a conductive cable. The recorder initiates the signal to be transmitted by the transducers and after a period of time, depending on the distance the signal travels, the reflected return

signal is received and appears as a darkened area on the chart recorder. The more reflective the object illuminated by the signal is, the darker the object appears on the record. Directly behind this return appears a shadow area, the size of which is dependent upon the size of the object illuminated, the angle of the signal to the object, and the angle of the slope behind the object. The various shades of gray indicate changes in texture and relief on the bottom (Patterson and Pope 1983).

49. A major concern in the application of the side-scan sonar technique to observe underwater structures along coastal slopes is the resolution offered. Since the goal of the inspection work is to assess the condition, coverage, or damage, good resolution is desirable. In one successful case, a 500-kHz transducer* was selected for this purpose because it demonstrated the capability to resolve substantial details of objects lying on the slope. It is also important that the "fish" is fixed in relation to the boat or the water surface, otherwise elevations at the bottom are not attainable. Bottom elevations may be desirable to monitor degree of deterioration from known elevations.

50. Side-scan sonar has become a widely used tool in numerous ocean applications since its introduction in the late 1950's. Its unique ability to rapidly produce photographlike images of the seafloor makes it the instrument of choice in searching for lost objects or for mapping of the bottom.

51. In the past several years, the side-scan technique has been used to map surfaces other than the ocean bottom. Successful trials have been conducted on the slopes of ice islands and breakwaters and on vertical pier structures (Mazel 1984).

52. The results and conclusions to the side-scan sonar survey of underwater structures indicated that this technology is both possible and practical in documenting construction as well as change occurring to the structure being studied. The side-scan sonar technique permits a valuable broad-scale view of the underwater structure that has not been obtained by any other means. The results are proven to be repeatable, and sequential surveys can be used for monitoring the condition of the structure throughout its service life by a

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* One of the commercially available models is the Klein Associates Model 422S-101EF, 500-kHz sonar. A Klein Model 612 Alphanumeric Annotator/Digital Expansion Unit is also available to annotate the field records and to expand the data.

comparison of the records from surveys. Although individual details are not always discernible on the sonograph, the resolution is usually sufficient to establish the pattern and to detect irregularities within that pattern.

53. Further applications of side-scan sonar to underwater engineering are: quality control during and after construction, site reconnaissance to define existing structure and site features, and monitoring change to existing structures by periodic comparison to determine failure or observe major changes. The side-scan sonar technology has progressed to offer the engineering community a valuable tool with which to assess the quality and performance of underwater structures. With the development of a new technology, it is quite possible that this tool can be adapted to the evaluation of underwater repair of concrete structures.

Radar

54. Certain types of radar have been used to evaluate the condition of concrete up to 30 in. in depth. Radar can differentiate between intact concrete and deteriorated concrete. The deterioration can be in the form of delaminations, microcracks, and structural cracks. Radar can also detect material changes and their locations (Alongi, Cantor, and Alongi 1982).

55. The ability of radar to identify the condition of concrete above water has been established. There are no references describing radar evaluation of underwater concrete. Members of the staff of the Cold Regions Research and Engineering Laboratory (CRREL) successfully used impulse radar to locate the "black box" lost in the Potomac River after the Air Florida jet hit the bridge near Washington, DC, in January 1982. In September 1985, USAEWES and CRREL staff members worked together in an initial attempt to locate and determine the condition of underwater articulated concrete mattresses used for bank erosion control in the Mississippi River (Thornton and Alexander 1987).

56. The discussion in paragraphs 52 and 53 indicates that the use of radar as an underwater inspection tool may certainly be feasible. However, further research is needed in this area.

Laser mapping

57. The invention of the laser and subsequent advancements in measurement technology have made possible a promising new mapping technique that has the potential to dramatically improve the capability to map topographic features. Previously it was impractical to acquire this information over large areas. Laser systems are capable of making extremely accurate distance

measurements. Airborne laser mapping systems have been examined for applicability in terrain surface mapping, bathymetry, and water quality.

58. The ability to accomplish terrain bathymetric mapping (in reasonably clear water) has been demonstrated. However, the development of laser systems is not at a level applicable to small projects such as underwater concrete repair. At the present time there are problems with positioning and resolution of short paths. Future developments in laser technology (as applied to bathymetry) may solve these problems and make the laser a technically and economically feasible tool for underwater evaluation applications.

High-resolution acoustic mapping system

59. A high-resolution acoustic mapping system (HRAM) was developed by WES (Thornton and Alexander 1987). The system was designed to provide, without dewatering, an accurate and comprehensive evaluation of top surface wear on horizontal surfaces (such as aprons, sills, lock chamber floors, and stilling basins) where turbulent water flow carrying rocks and debris may have caused erosion or abrasion damage.

60. Unlike the acoustic systems (echosounder and side-scan sonar) that provide broad coverage, the HRAM uses high-frequency transducers mounted on a near-surface platform. The resultant narrow acoustic beams can see into depressions and close to vertical surfaces. The high-frequency transducers also provide high resolution. Vertical profiling accuracy ranges between ± 1 and 6 in. in 10- to 200-ft water depths, respectively.

61. This system has been used at four US Army Engineer dams to map stilling basin abrasion loss. It has also been used successfully to locate slope slippage in a reservoir. With the high-resolution transducers and ability to profile near vertical surfaces in any water depth, this system appears to be ideal for inspecting underwater concrete repairs.

PART V: CONCLUSIONS

Concrete Mixtures and Placement Techniques

62. The results of these tests indicate that cohesive, flowable, and abrasion-resistant concrete can be placed underwater by available methods without use of the tremie seal and with minimal loss of fines if proper materials are used and precautions are taken. A successful repair was made at Red Rock Dam near Des Moines, IA, in 1988 (Appendix A). AWA and silica fume can be used to reduce segregation and dilution with the water. AWA will reduce washout of fines in fresh concrete allowed to free-fall through 3 ft of water, but dilution will occur. Thus, this technique is not recommended for repair of underwater concrete. The degree of workability and washout resistance necessary for a successful concrete placement will depend upon the type of equipment used in the placement.

63. Concrete containing AWA and WRA and placed at the point of use will bond securely to hardened concrete and sustain only relatively small loss of fines if the bonding surface is clean. Even so, anchors should probably be used to ensure that the new concrete remains in place. It is unlikely that the bond will be as satisfactory in an actual repair as in the laboratory due to difficulties in cleaning the old concrete surfaces. Fluid concrete with good cohesion will move laterally for short distances, again with only minimal dilution. Concrete so placed can be worked underwater to a rough finish. As with any underwater concrete work, agitation and movement should be minimized. Indications are that abrasion resistance of concrete placed and finished underwater equals that of concrete placed in air once the laitance is abraded from the surface.

64. The thickness of the underwater repair will be limited due to thermal stresses associated with the high cementitious material content of the concretes. The maximum allowable thickness of the repair concrete should be determined by thermal stress considerations prior to the concrete placement. Multiple layers of concrete could be used if the repair area is deeper than thermal conditions will allow to be filled in one layer. The thickness of the layer, or layers, of abrasion-resistant underwater concrete should be relatively uniform. Void areas that are deep, relative to the repair as a whole, should be filled with an underwater concrete having a lower cementitious

material content to an average level of the repair area.

Inspection Techniques

65. There are a number of inspection techniques that can evaluate the degree of success obtained in repairing concrete structures underwater. Type, size, location, and environmental conditions of a particular repair job, along with technique capabilities and limitations and cost considerations, will affect the selection of inspection techniques.

66. In clear or moderately turbid water with a nominal "friendly" environment, visual inspection by a diver with or without a video camera may be entirely suitable. In some cases, an underwater telescope may suffice. If the water is clear or moderately turbid, but the environment is somewhat "hostile," i.e. strong currents, or very deep or cold water, it may be necessary to use a suitable ROV with video camera.

67. In very turbid water where visibility is poor, the diver may be able to perform a tactile inspection that will provide sufficient evidence that the problem area has been satisfactorily repaired.

68. Echosounders and side-scan sonar may be used in situations unsuitable for visual (diver or ROV) or tactile (diver) inspection. These situations may include high turbidity, deep or cold water, strong currents, or jobs where permanent records are desired for future use. It should be remembered that these techniques are not recommended for inspection of repair of small areas, repair near vertical surfaces, or repair where high-resolution (plus or minus a few inches) records are desired. In situations where large area, deep repair is performed, the echosounder or side-scan sonar may serve to give large-scale indications of repair results.

69. Investigations performed using radar and laser technology have produced promising results indicating that these techniques may be applied to evaluating the success of underwater repair. However, existing experimental data allow only the conclusion that the use of these techniques for inspection of underwater repair is feasible.

70. The HRAM can be adapted to almost any situation where underwater repair of concrete is accomplished. The transducer array can map a wide (10- to 20-ft), medium (5- to 10-ft), or narrow (1- to 5-ft) swath. The high-frequency, narrow-beam transducers can see into narrow depressions and can

operate near to vertical surfaces. Vertical resolution ranges between ± 1 and 6 in. in water depths of 10 to 200 ft, respectively. Computer controlled lateral positioning, various forms of hard copy (including real time), and operational versatility make the HRAM an ideal system for inspection of underwater repair.

REFERENCES

Alongi, A. V., Cantor, T. R., and Alongi, A., Jr. 1982. "Concrete Evaluation by Radar Theoretical Analysis," Concrete Analysis and Deterioration, Transportation Research Board Record No. 853, pp 31-37, Transportation Research Board, Washington, DC.

American Society for Testing and Materials. 1987. "Concrete and Mineral Aggregates," 1987 Annual Book of ASTM Standards, Vol 04.02, Section 4, Philadelphia, PA.

Gerwick, B. C. 1988 (Sep). "Review of the State of the Art for Underwater Repair Using Abrasion-Resistant Concrete," Technical Report REMR-CS-19, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Holland, T. C. 1983 (Sep). "Abrasion-Erosion Evaluation of Concrete Mixtures for Stilling Basin Repairs, Kinzua Dam, Pennsylvania," Miscellaneous Paper SL-83-16, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Marine Technology Society. 1984. Operational Guidelines for Remotely Operated Vehicles, Washington, DC.

__________. 1985. ROV '85, San Diego, CA.

Mazel, C. H. 1984 (14-17 May). "Inspection of Surfaces by Side-Scan Sonar," ROV '84, Marine Technology Society, Washington, DC.

McDonald, J. E. 1980 (Apr). "Maintenance and Preservation of Concrete Structures; Repair of Erosion-Damaged Structures," Technical Report C-78-4, Report 2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Neeley, B. D. 1988 (Apr). "Evaluation of Concrete Mixtures for Use in Underwater Repairs," Technical Report REMR-CS-18, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. 1989 (Mar). "Antiwash Admixtures for Use in Underwater Concrete Placement," Video Report REMR-CS-3, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Patterson, D. R., and Pope, J. 1983. "Coastal Applications of Side Scan Sonar," Coastal Structures '83, J. R. Weggel, ed., American Society of Civil Engineers, pp 902-910.

Reichmuth, D. R. 1963. "Correlations of Force-Displacement Data with Physical Properties of Rock for Percussive Drilling Systems," Proceedings of the Symposium on Rock Mechanics, 5th ed., Macmillan, New York, p 33.

Robins, P. J. 1980 (Jun). "The Point-Load Strength Test for Concrete Cores," Magazine of Concrete Research, Vol 32, No. 111, pp 101-111.

Saucier, K. L., and Neeley, B. D. 1987 (May). "Antiwashout Admixtures in Underwater Concrete," Concrete International: Design and Construction, Vol 9, No. 5, pp 42-47.

Tattersall, G. H., and Banfill, P. F. G. 1983. The Rheology of Fresh Concrete, Pittman, Boston, MA.

Thornton, H. T., and Alexander, A. M. 1987 (Dec). "Development of Nondestructive Testing Systems For In Situ Evaluation of Concrete Structures," Technical Report REMR-CS-10, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

US Army Engineer Waterways Experiment Station. 1949 (Aug). Handbook for Concrete and Cement (with quarterly supplements), Vicksburg, MS.

Table 1

Test Matrix

Trial No.	Concrete Mixture	Concrete Containment	Type Placement
1	12CON	Beam, tank, and abrasion	Truck chute, free-fall
2	87	Beam, tank, and abrasion	Truck chute, free-fall
3	87	Beam, tank, large box, and abrasion	Pump
4	78	Beam, tank, large box, and abrasion	Pump
5	78	Beam, large box, and abrasion	Bucket with chute
6	87	Beam, large box, and abrasion	Inclined tremie and pump
7	79	Large box and abrasion	Inclined tremie
8	80		
9	101		
10	12CON		
11	102		
12	103	Large box	Bucket
13	104	Large box	Bucket
14	105	Large box	Inclined tremie
15	106	Large box	Inclined tremie
16	107	Small box	Chute, free-fall
17	108	Small box	Chute, free-fall
18	109	Small box	Chute, free-fall

Table 2

Concrete Mixture Proportions

Mix No.	W/C	HRWRA*	Dosage oz/cu yd	AWA	Dosage lb/cu yd	AEA oz/cu yd	D-Air 1 lb/cu yd	Cement lb/cu yd	Silica Fume lb/cu yd	Fly Ash lb/cu yd	Fine Aggregate lb/cu yd	Coarse Aggregate lb/cu yd	Water lb/cu yd
12CON	0.36	LIG	143	None	None	None	None	590	89	None	1,405	1,671	238
87	↓	↓	170	A	0.68	↓	0.68	↓	↓	↓	↓	↓	↓
78	↓	↓	170	D	6.79	↓	0.68	↓	↓	↓	↓	↓	↓
79	↓	↓	258	C	13.58	↓	0.68	↓	↓	↓	↓	↓	↓
80	↓	↓	170	B	3.40	↓	0.68	↓	↓	↓	↓	↓	↓
101	0.45	HCA	14	None	None	5.0	None	705	None	↓	1,282	1,525	319
102	0.30	LIG	400	B	5.00	None	2.80	850	150	↓	1,489	1,185	300
103	0.44	LIG	168	B	7.70	↓	0.70	700	None	↓	1,281	1,650	308
104	0.40	NAP	4.2**	B	1.05	↓	0.70	700	↓	↓	1,281	1,650	280
105	0.38	LIG	200	B	6.00	↓	0.80	600	↓	200	1,407	1,370	304
106	0.50	None	None	B	9.80	↓	None	500	↓	200	1,248	1,485	350
107	0.48	LIG	180	F	12.0	↓	0.90	600	↓	300	1,067	1,269	432
108	0.65	LIG	42	F	12.0	↓	0.70	350	↓	350	1,179	1,294	455
109	0.47	LIG	72	F	12.0	↓	0.90	600	↓	300	1,101	1,310	420

Note: W/C = Water-cement ratio
HRWRA = High-range water-reducing admixtures
AWA = Antiwashout admixtures
AEA = Air-entraining agent

* HCA = hydroxylated carboxylic acid
LIG = lignosulfonate
NAP = naphthalene sulfonate

** lb/cu yd

Table 3

Results of Tests on Fresh Concrete

Trial No.	Mix No.	Slump in.	Air Content %	Tremie Flow in.	Two-Point Workability g*	Two-Point Workability h*	Washout %	Observations of Placement: Self-Leveling Concrete	Observations of Placement: Condition of Water after Placement	Observations of Placement: Workability of Concrete
1	12CON	8-1/2	1.3	17	1.67	0.68	6.0	Yes	Muddy	Good
2	87	8-3/4	2.2	NA	1.78	0.85	2.1	No	Cloudy	Good
3	87	5-1/2	2.3	10-3/4	3.94	1.13	0.8	No	Cloudy	Fair
4	78	8	1.9	19-1/4	1.83	1.04	2.7	No	Cloudy	Good
5	78	3	1.9	6-1/2	4.25	0.87	0.2	No	Clear	Poor
6	87	8	1.4	17	2.59	1.13	2.9	Yes	Cloudy	Good
7	79	8	2.7	13-1/4	4.54	1.59	0.8	No	Clear	Fair
8	80	9	2.8	15-1/2	4.07	2.25	1.6	No	Clear	Good
9	101	8-1/2	6.6	17	2.18	0.73	9.8	Yes	Muddy	
10	12CON	7-1/4	1.8	13	3.56	1.08	3.0	No	Clear	
11	102	8-1/2	1.3	16	1.37	0.91	0.8	Yes	Clear	
12	103	7-3/4	NA	19-3/4	4.95	3.42	2.5	No	Cloudy	
13	104	7-3/4	9.5	20-3/4	2.19	0.83	10.2	Yes	Muddy	
14	105	10-1/2	2.3	23-1/2	2.17	1.68	--		Clear	
15	106	10-1/4	9.8	19-1/2	1.56	2.27	--		Cloudy	
16	107	10-1/2	1.1	24	NA	NA	--		Cloudy	
17	108	11	1.0	24	NA	NA	--		Cloudy	
18	109	10-1/2	1.5	22-1/2	NA	NA	--		Cloudy	

Note: -- indicates test not run; concrete was so fluid that the cement paste seeped through the holes in the basket continuously.

NA indicates test results were not available.

* g and h are the two nondimensional results of the two-point workability test.

Table 4

Results of Tests on Hardened Concrete*

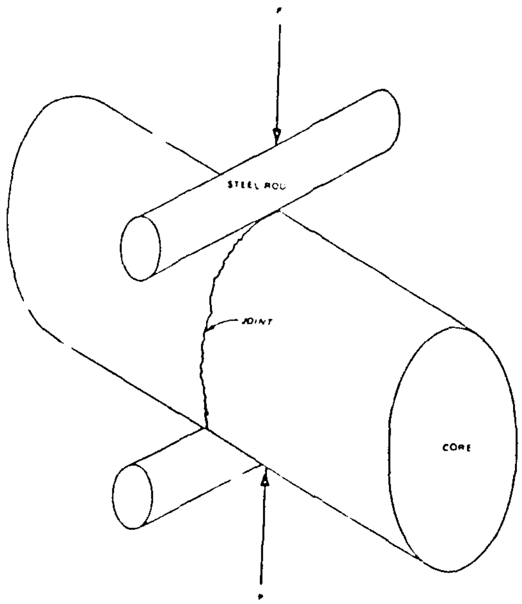
Trial No.	Mix No.	Tensile Strength, psi Old Concrete	Tensile Strength, psi New Concrete	Bond Strength psi	Bond Strength Percentage of New Concrete Strength	Abrasion-Erosion Loss cm^3/cm^2 at 72 hr Screeded	Abrasion-Erosion Loss cm^3/cm^2 at 72 hr Cut	Abrasion-Erosion Loss cm^3/cm^2 at 72 hr Air**	Compressive Strength, psi Cyliners**	Compressive Strength, psi Cores†
1	12CON	NA	NA	NA	NA	0.637	0.431	0.340	8,320	NA
2	87	410	195	185	95	0.481	0.357	0.316	9,310	8,810
3	87	445	470	240	51	NA	0.383	0.465	9,550	8,440
4	78	445	525	300	57	NA	0.232	0.311	9,000	8,200
5	78	NA	NA	NA	NA	NA	0.363	0.322	8,940	8,330
6	87	445	540	265	49	NA	0.205	0.342	8,870	8,660
7	79	380	405	210	52	0.357	NA	0.344	8,910	6,590
8	80	435	445	250	56	0.399		0.309	9,100	NA
9	101	310	230	265	115	0.579		0.379	3,990	
10	12CON	595	480	195	41	0.456		0.289	NA	
11	102	470	505	235	47	0.517		0.267	10,800	
12	103	355	445	100	22	NA		NA	6,770	
13	104	175	400	130	33				4,880	
14	105	335	350	285	81				5,360	
15	106	210	320	220	69				2,830	
16	107	455	155	215	139				3,400	2,880
17	108	405	60	120	200				920	800
18	109	420	220	205	93				3,690	3,230

Note: NA indicates test results were not available.

* Specimens cast underwater unless indicated otherwise; results average of minimum of two tests.

** 4-in.-diam by 8-in.-high cylinders cast in air.

† Cores taken from same location as specimens tested for bond strength.



where $T = P/D^2$

T = tensile strength, psi

P = failure load, lb

D = core diameter, in

Figure 1. Point-load tensile test

Figure 2. Concrete discharged into steel tank, trial 1

Figure 3. Completion of concrete placement into steel tank, trial 1

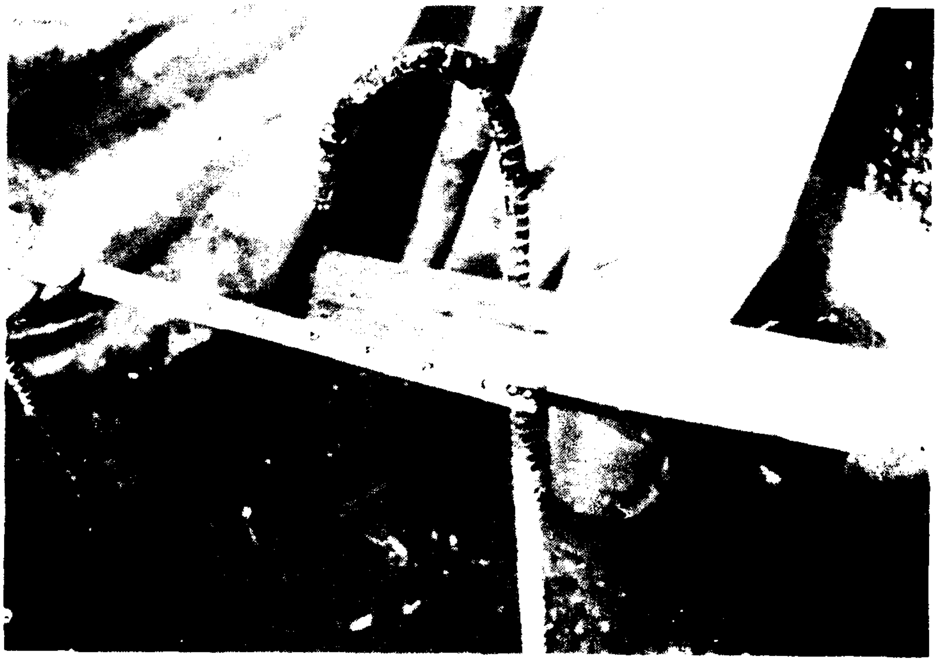


Figure 4. Weak mortar collected on top of concrete in steel tank, trial 1

Figure 5. Porous friable concrete after hardening, trial 1

Figure 6. Concrete discharged into beam mold, trial 1

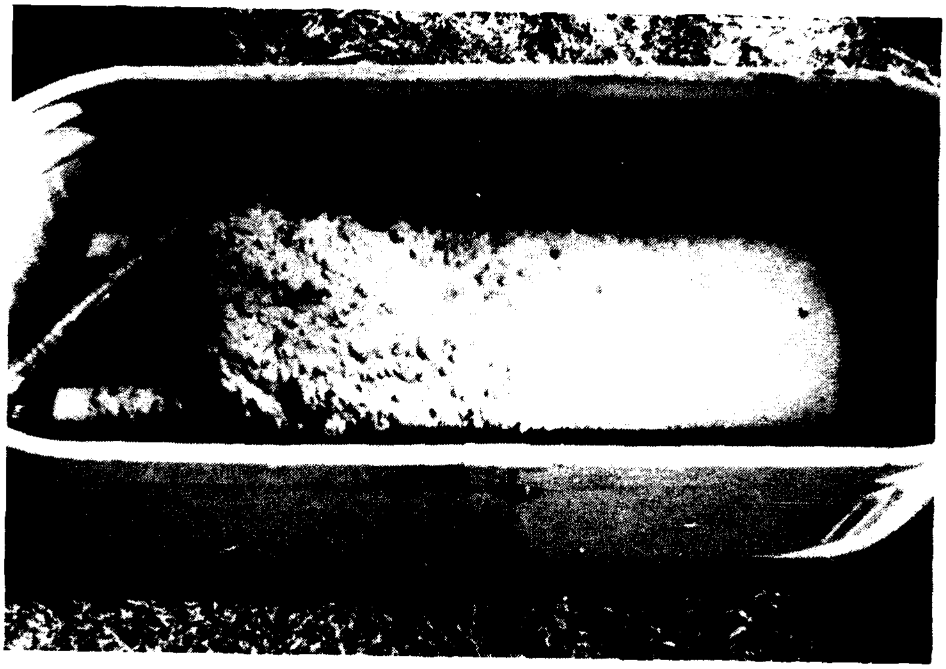


Figure 7. Concrete beam after hardening, trial 1

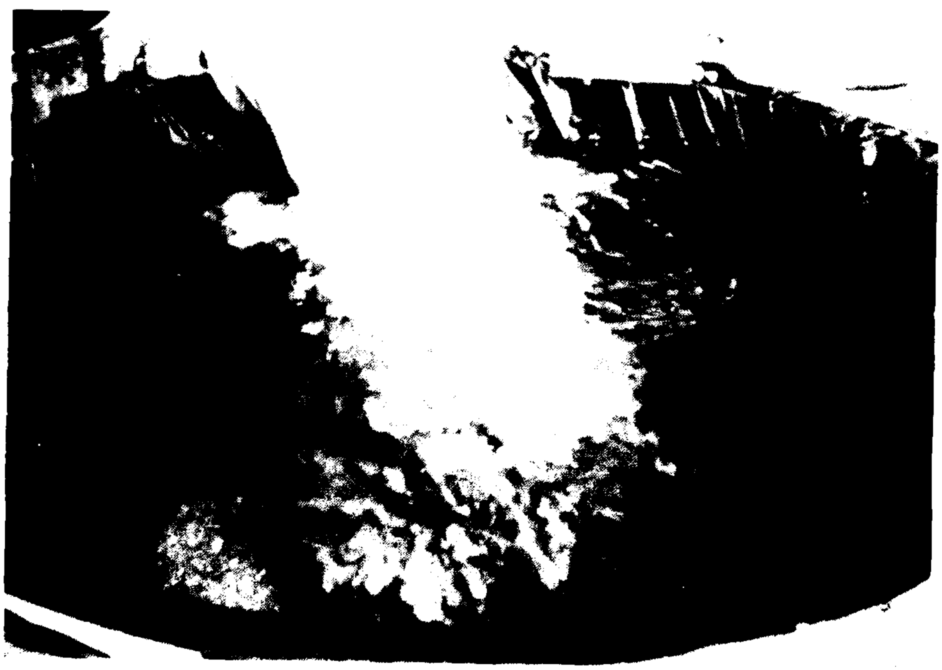


Figure 8. Concrete discharged into steel tank, trial 2

Figure 9. Completion of concrete placement into steel tank, trial 2

Figure 10. Solid mass of concrete after hardening, trial 2

Figure 11. Concrete discharged into beam mold, trial 2

Figure 12. Concrete beam after hardening, trial 2

Figure 13. Hardened abrasion specimens, trial 2

Figure 14. Concrete pumped into box, trial 3

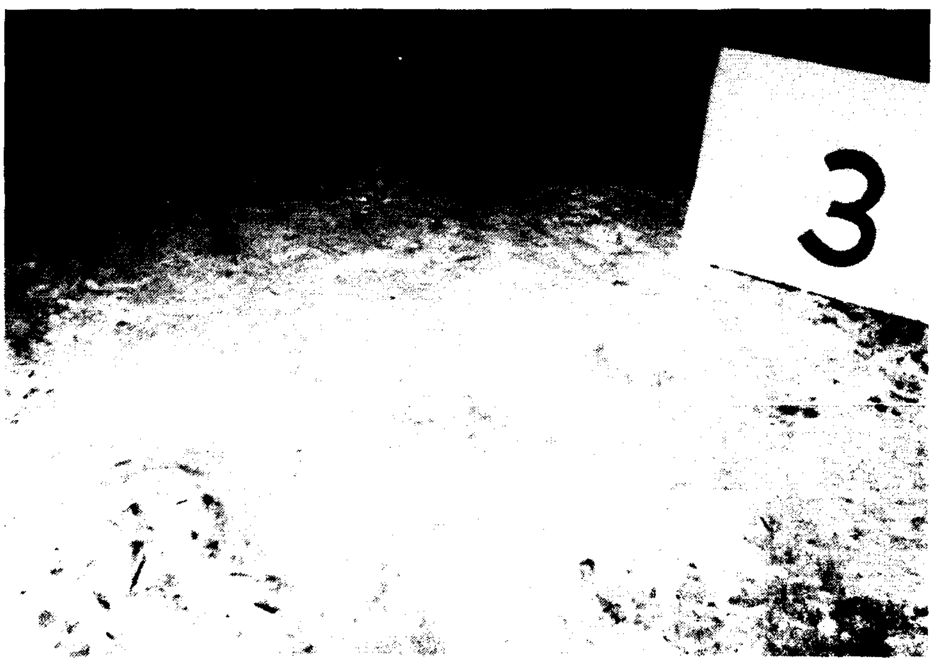


Figure 15. Screeded surface of concrete in box after hardening, trial 3

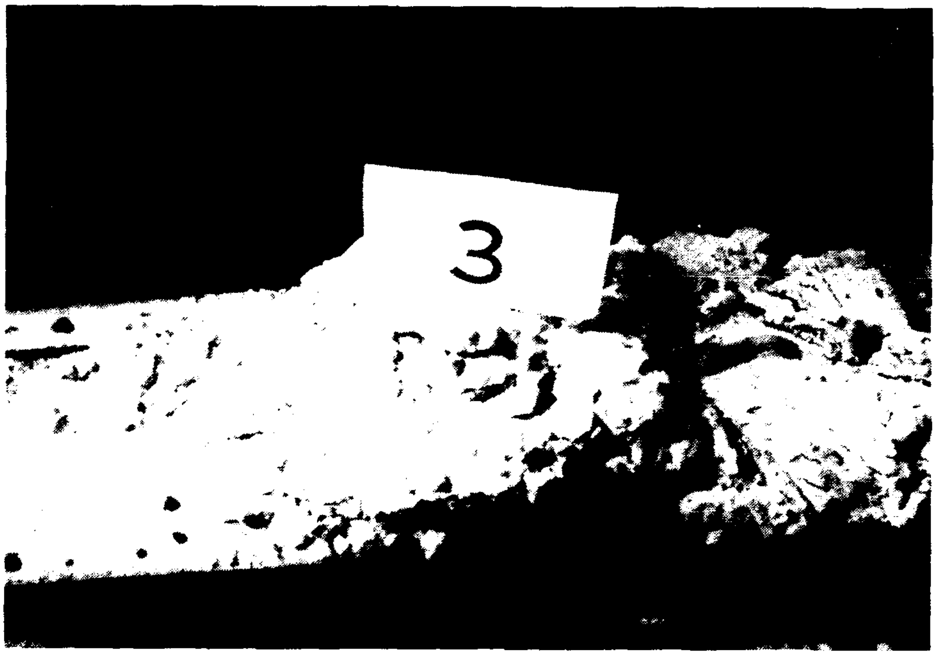


Figure 16. Concrete beam after hardening, trial 3

Figure 17. Concrete pumped into steel tank, trial 4

Figure 18. Concrete pumped into beam mold, trial 4

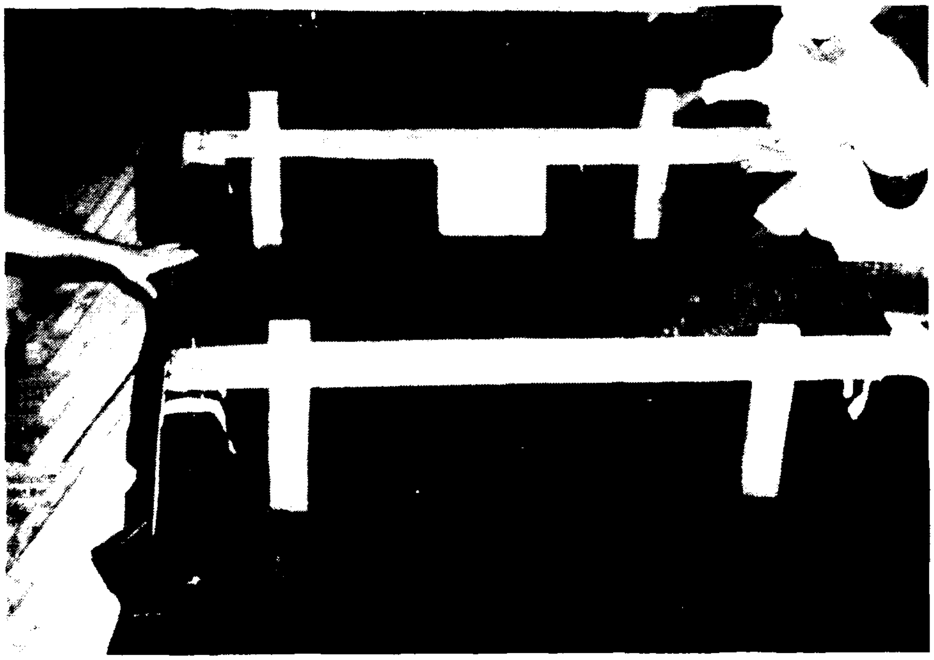


Figure 19. Concrete pumped into box, trial 4

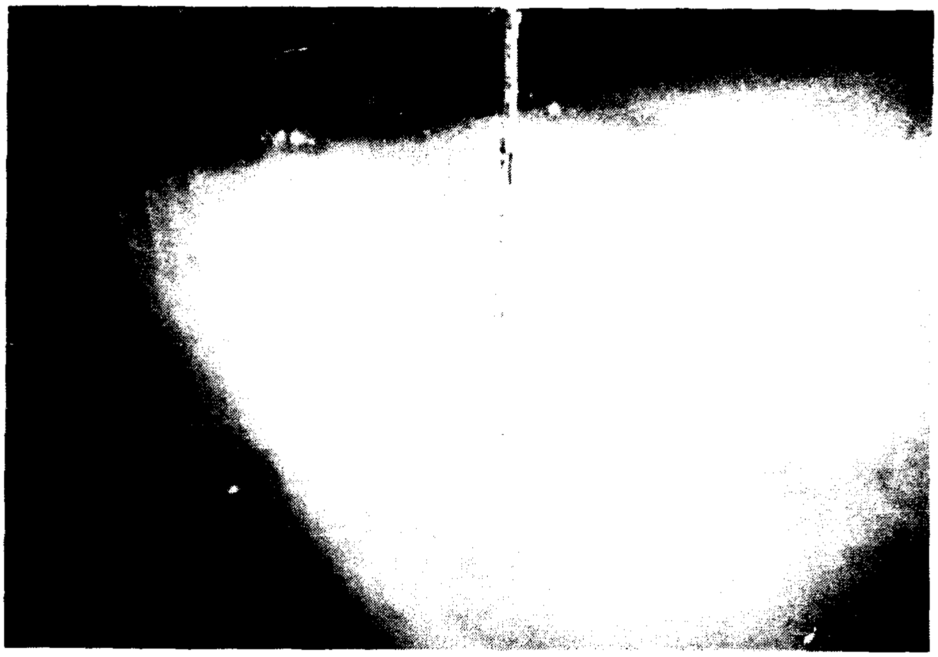


Figure 20. Concrete placement observed through
4 ft of water, trial 4

Figure 21. Hardened abrasion specimens, trial 4

Figure 22. Concrete placed into box with bucket and chute, trial 5

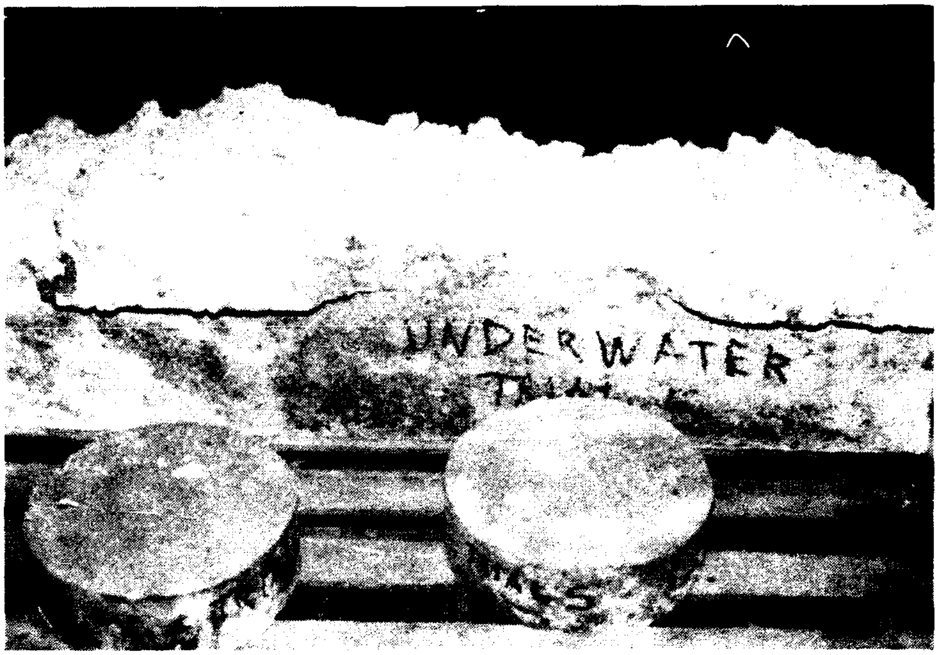


Figure 23. Hardened abrasion specimens and beam, trial 5

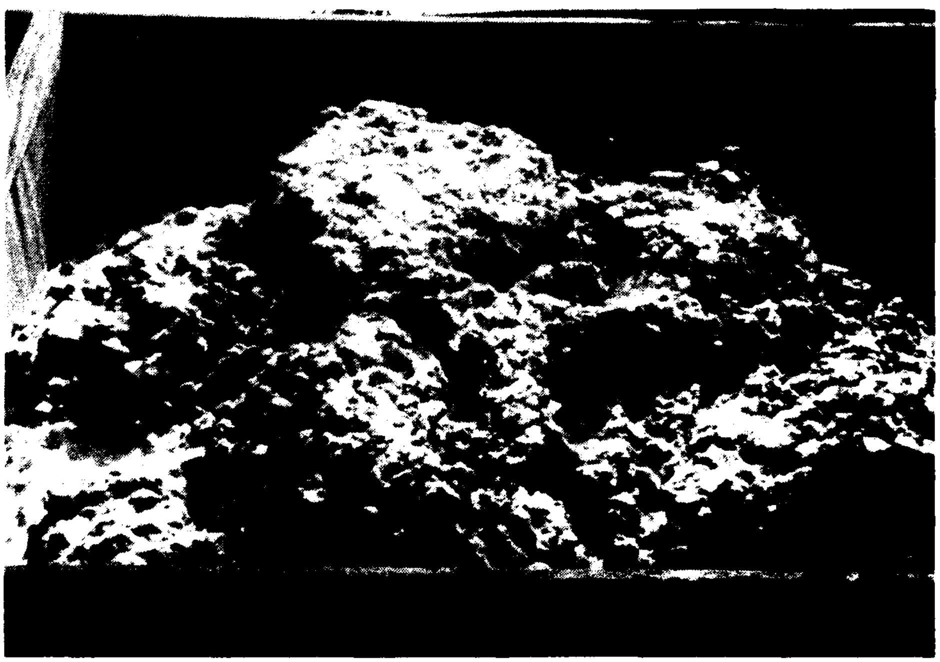


Figure 24. Concrete in box after hardening, trial 5

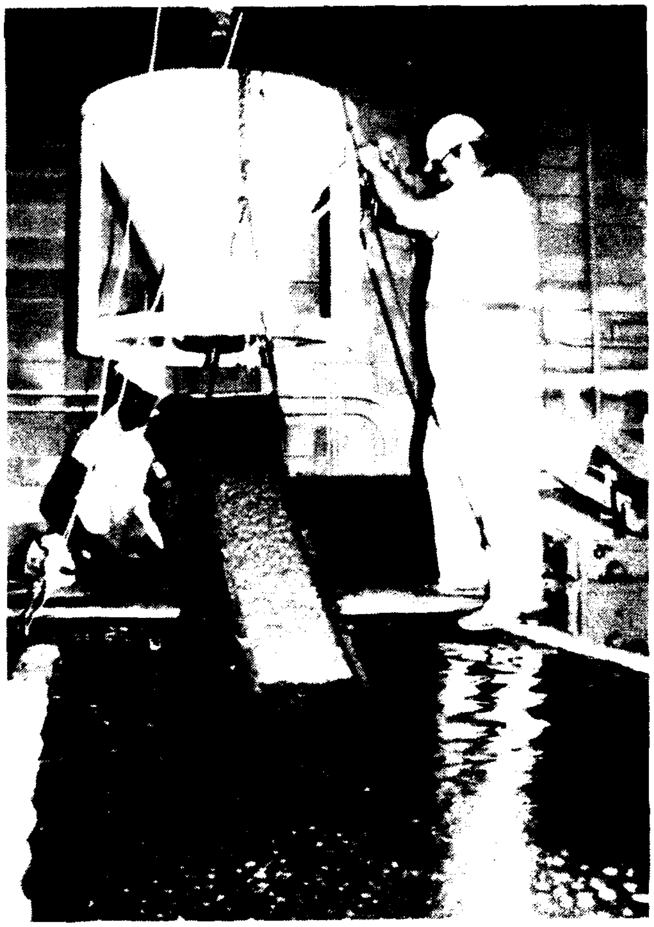


Figure 25. Inclined tremie used to fill box, trial 6

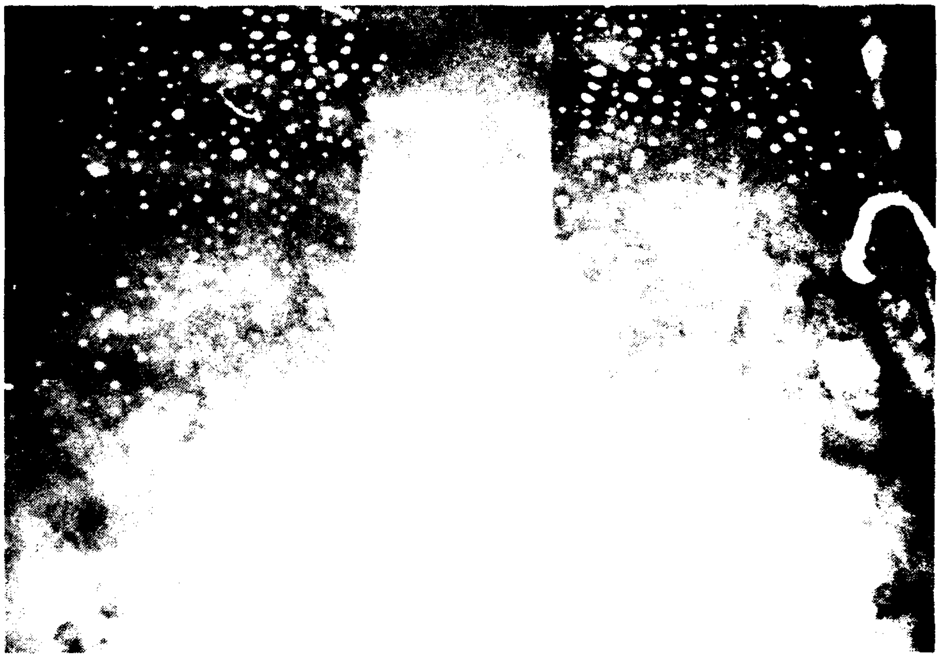


Figure 26. Concrete flowing from inclined tremie to fill box, trial 6

Figure 27. Concrete pumped into beam and abrasion molds, trial 6

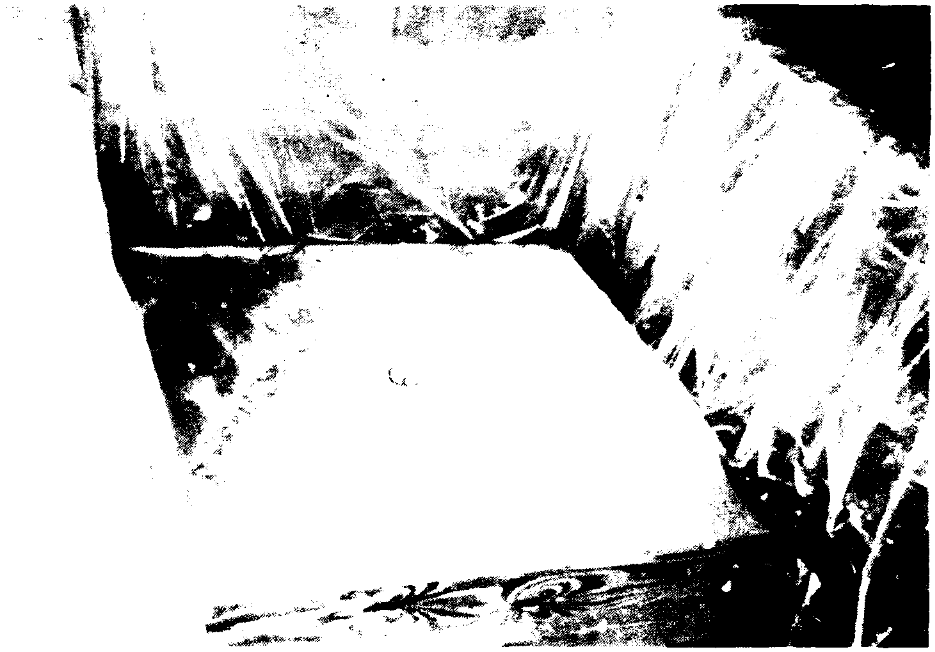


Figure 28. Screeded surface of concrete in box after hardening, trial 6

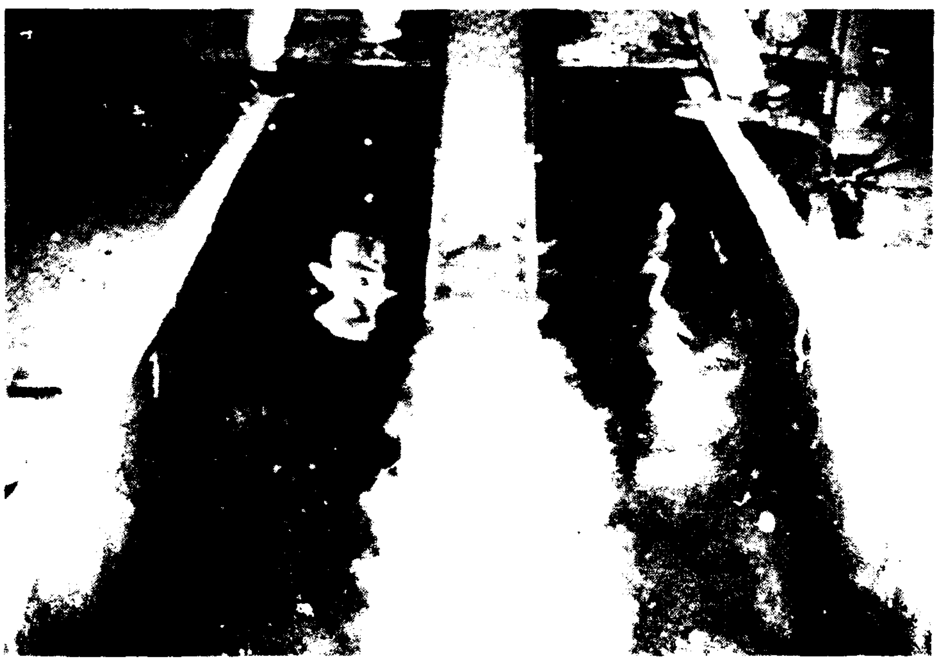


Figure 29. Clouding of water during concrete placement into box with inclined tremie, trial 9

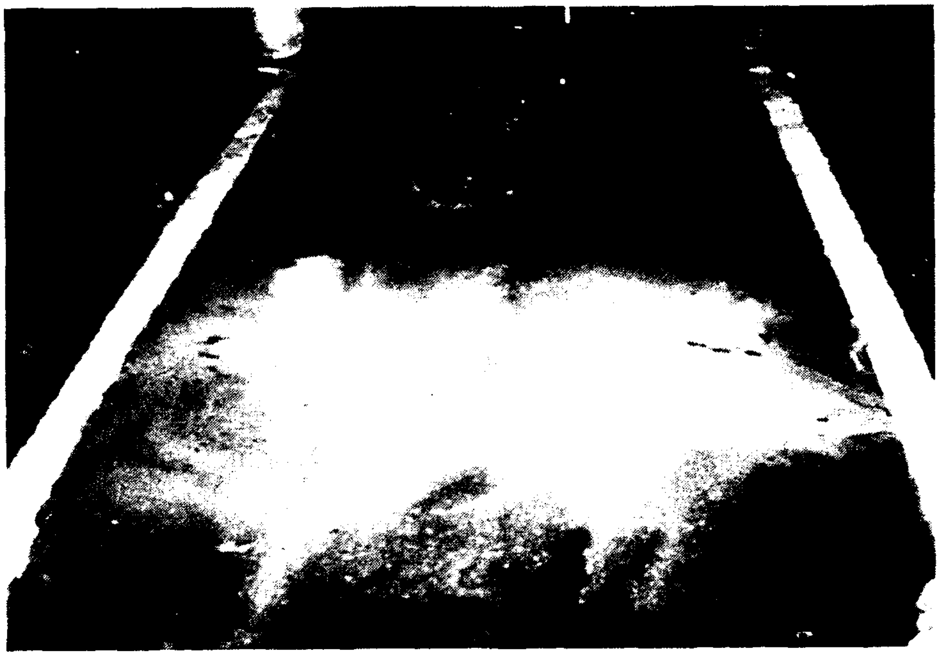


Figure 30. Froth collected on top of water after concrete placement, trial 9

Figure 31. Filling abrasion molds, trial 9

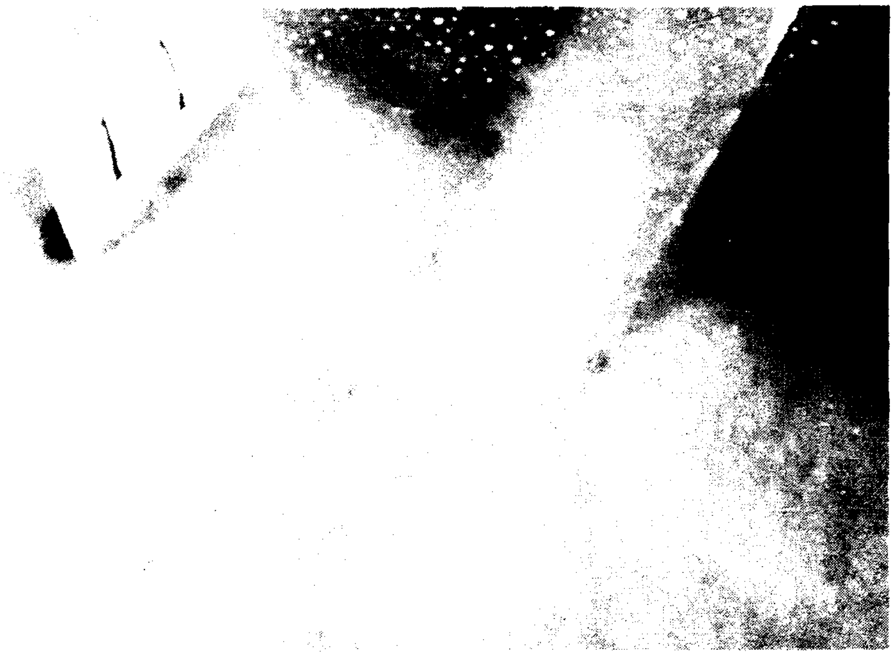


Figure 32. Concrete placement observed through 4 ft of water, trial 11

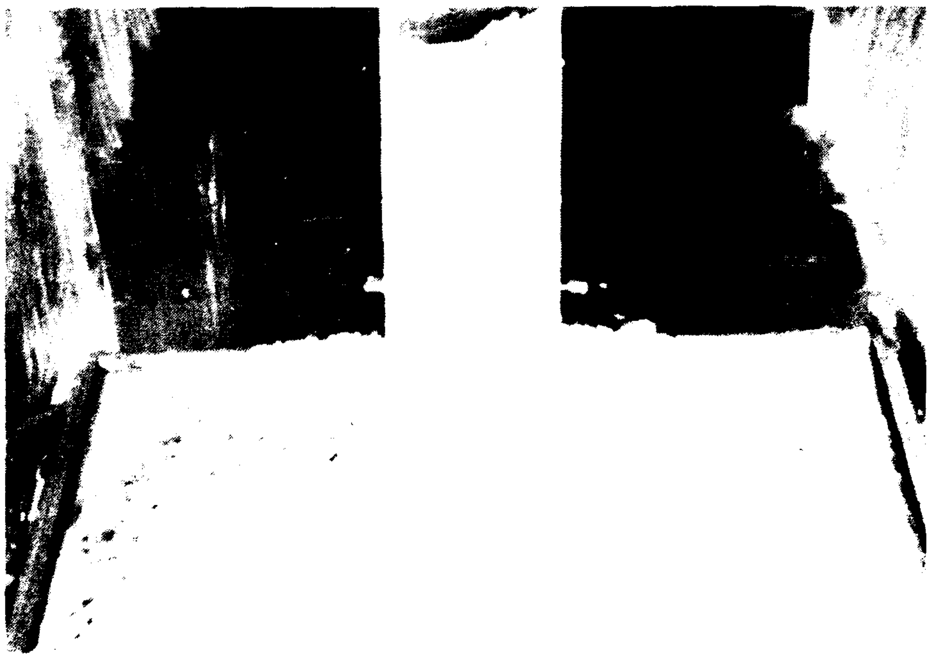


Figure 33. Concrete in box immediately after placement, trial 11

Figure 34. Filling abrasion molds, trial 11

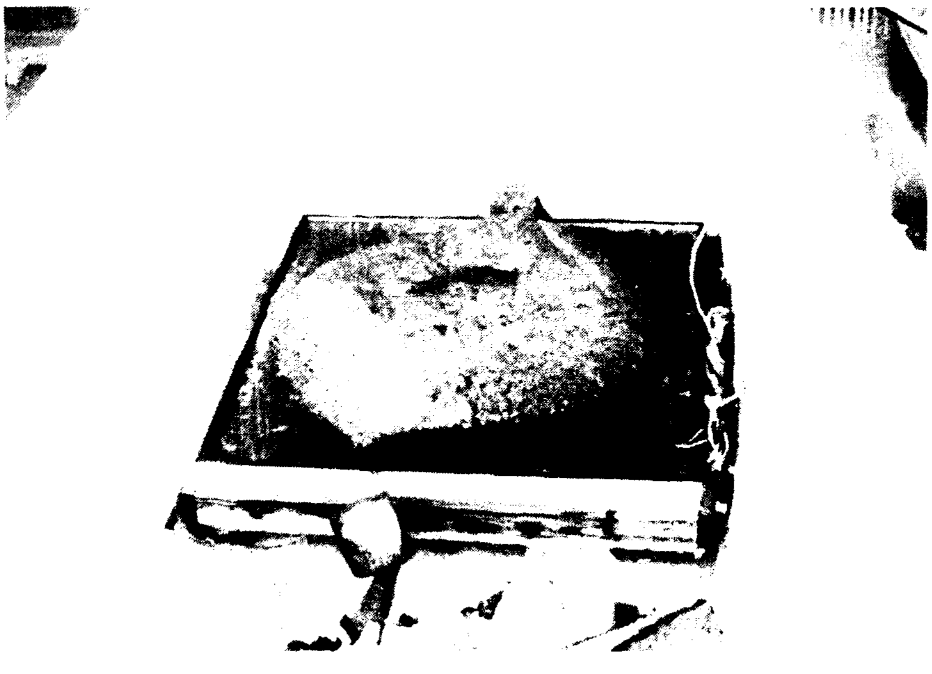


Figure 35. Concrete in box immediately after placement, trial 12

Figure 36. Placing concrete into box with bucket, trial 13

Figure 37. Froth collected on top of water after concrete placement, trial 13

Figure 38. Concrete in box immediately after placement, trial 13

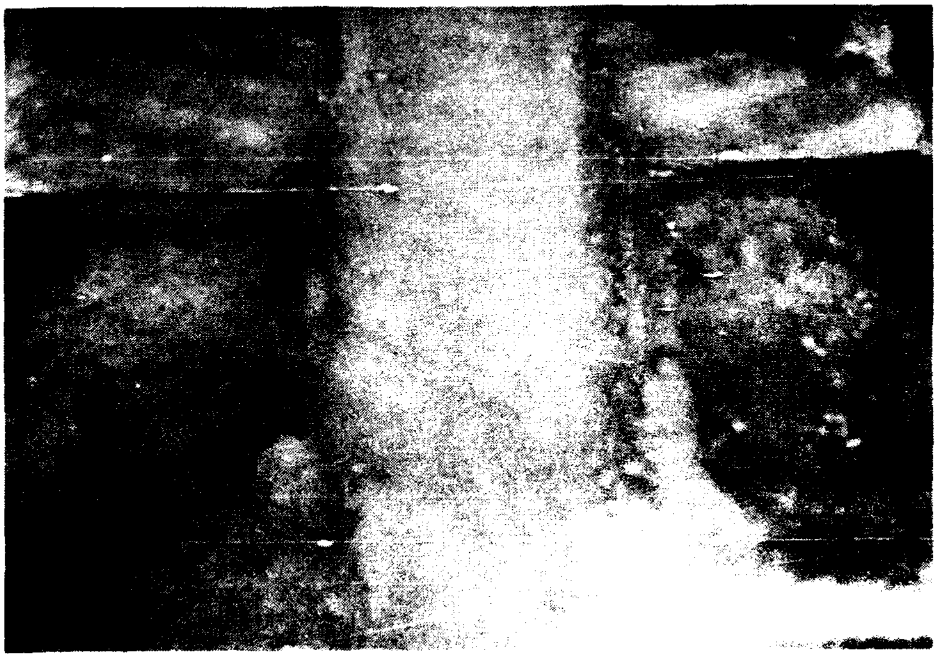


Figure 39. Concrete discharged into box with inclined tremie, trial 14

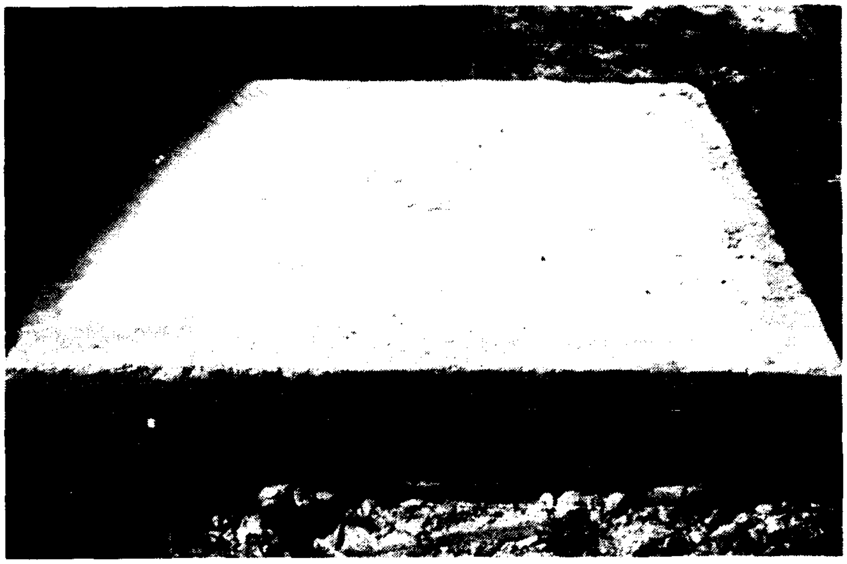


Figure 40. Concrete in box after hardening, trial 14

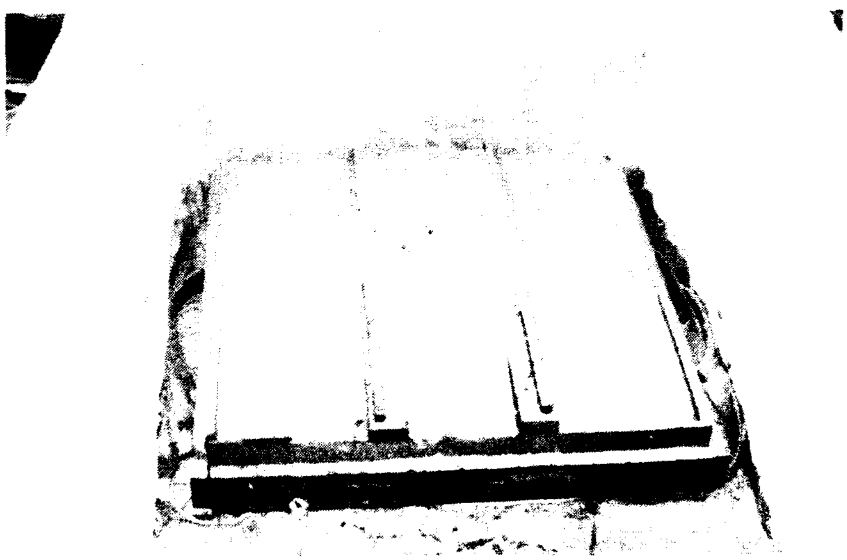


Figure 41. Concrete in box immediately after placement, trial 15

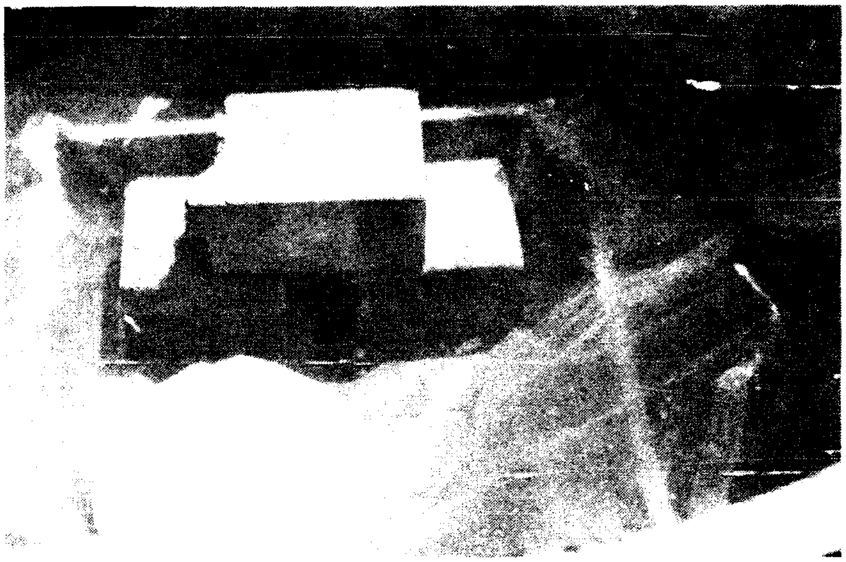


Figure 42. Containers prior to concrete placement, trial 16

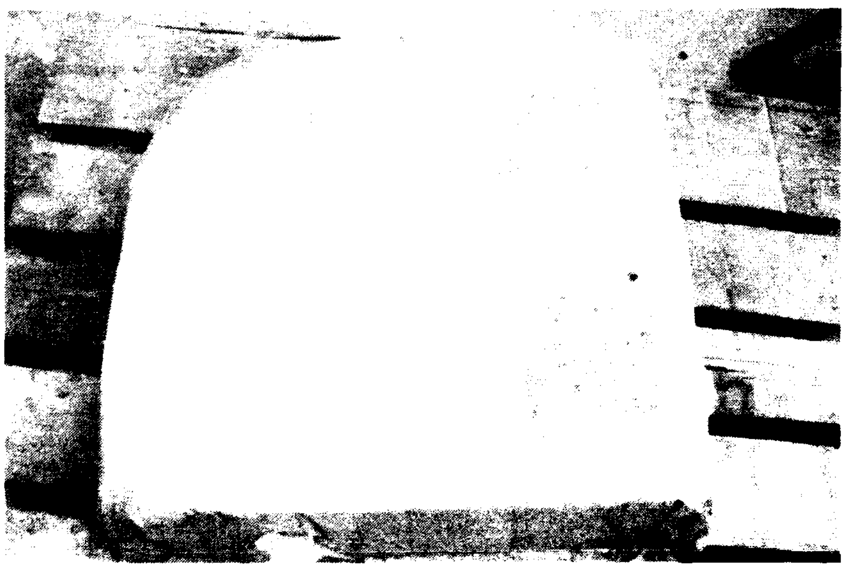


Figure 43. Hardened concrete after placement, trial 16

Figure 44. Concrete placed by free-fall through 3 ft of water, trial 17

Figure 45. Surface of water after concrete placement, trial 17

Figure 46. Slump of concrete immediately after pulling cone, trial 18

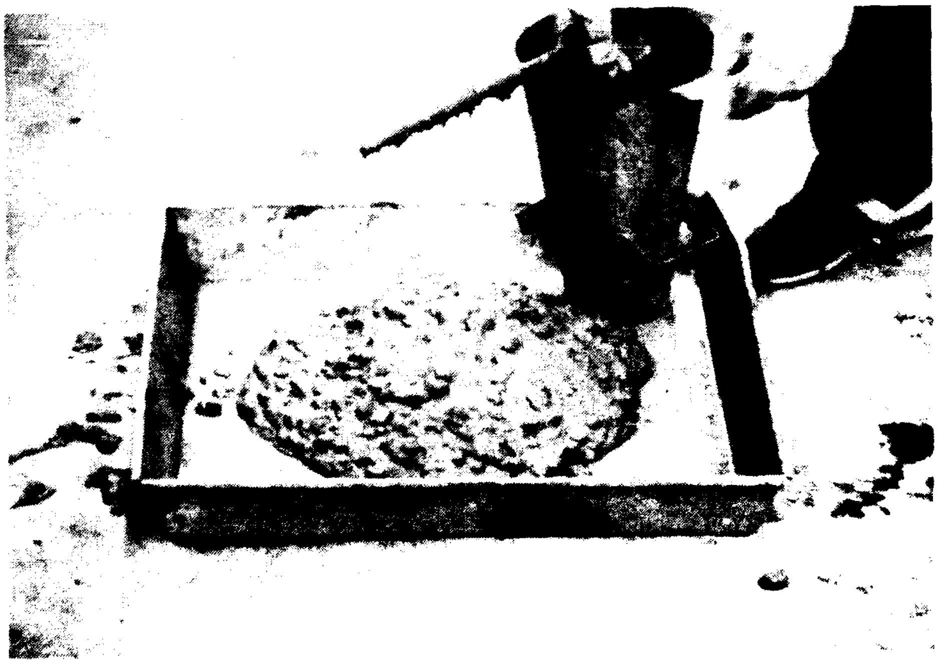


Figure 47. Slump of concrete 1 min after pulling cone, trial 18

Figure 48. Concrete placed by free-fall through 3 ft of water, trial 18

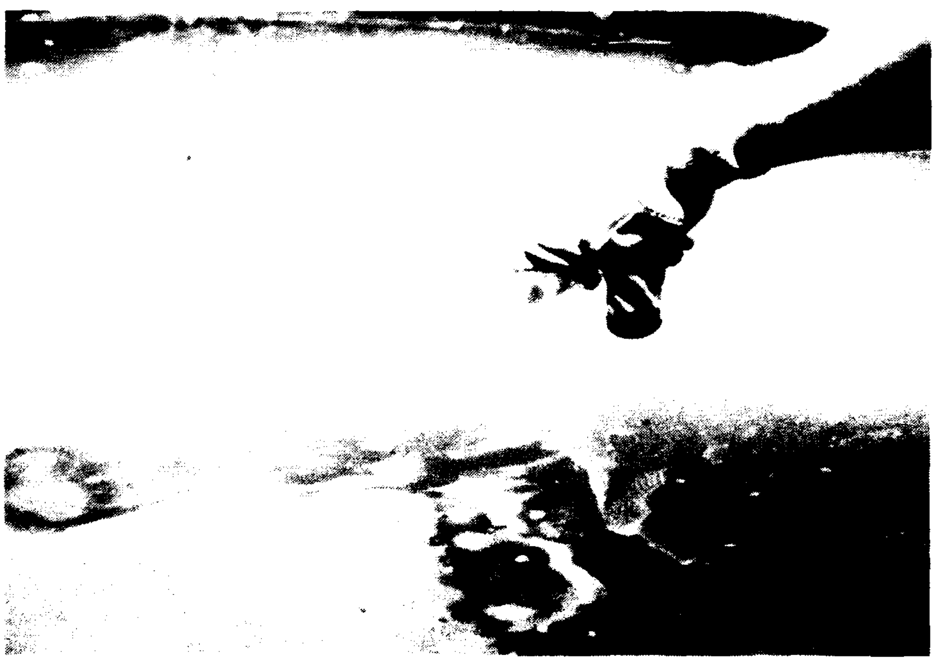


Figure 49. Surface of water after concrete placement, trial 18

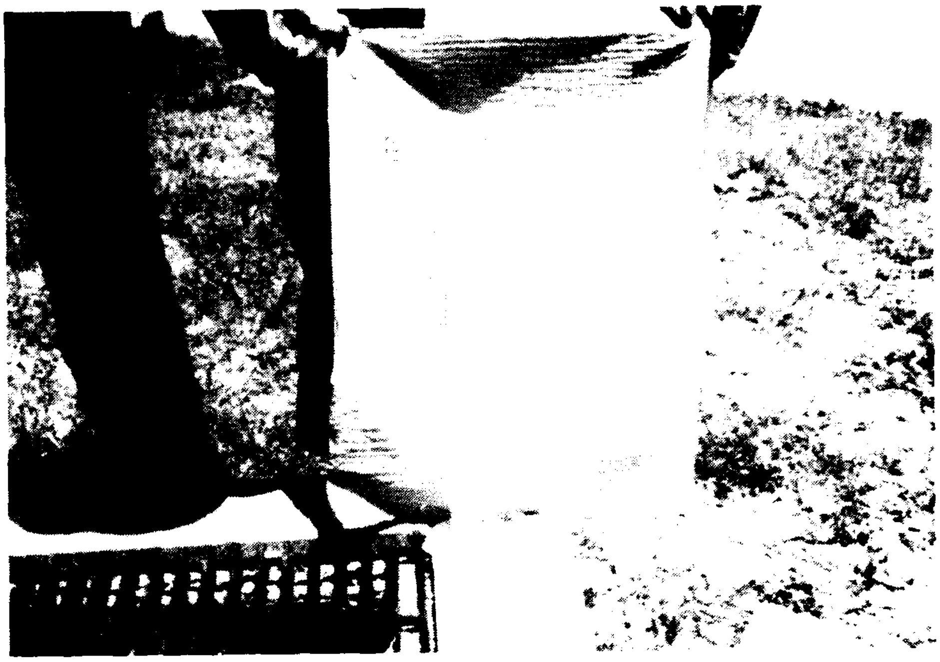


Figure 50. Water after concrete placement, trial 18

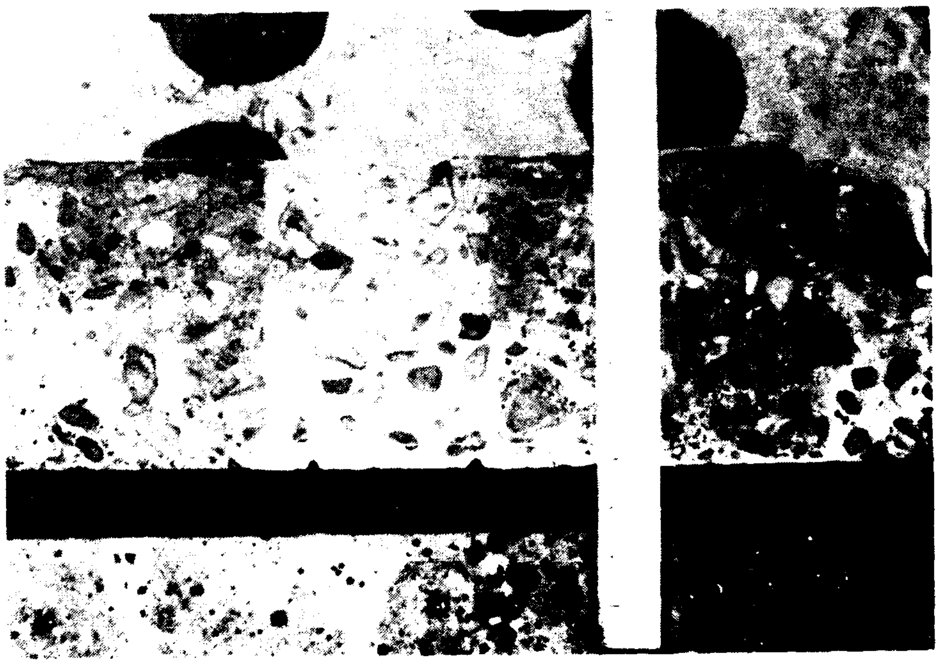


Figure 51. Hardened concrete after placement, trial 18

Figure 52. Washout sample after completion of test, trial 13

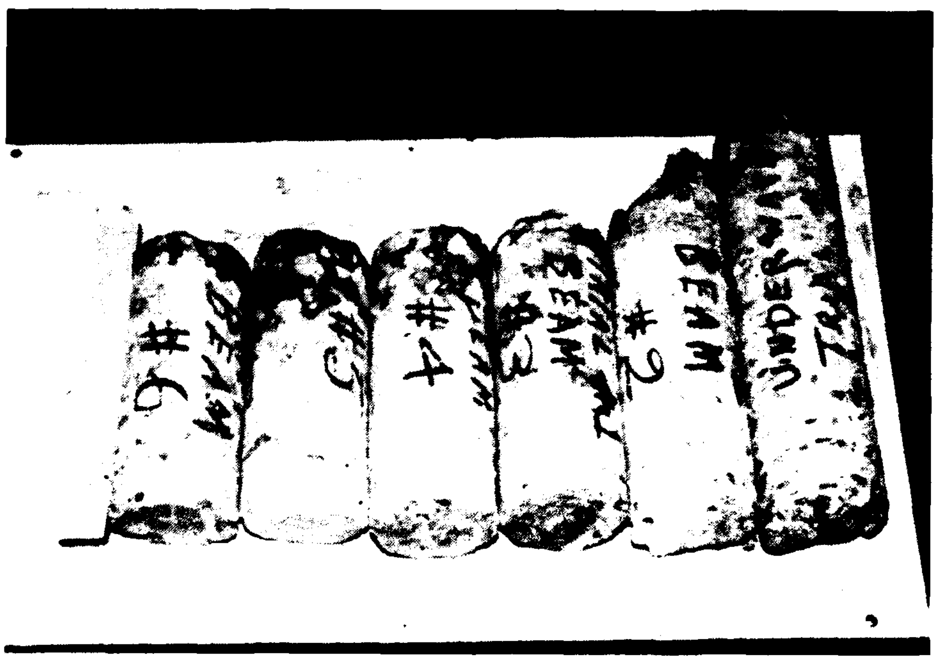


Figure 53. Cores from concrete beam, trial 1

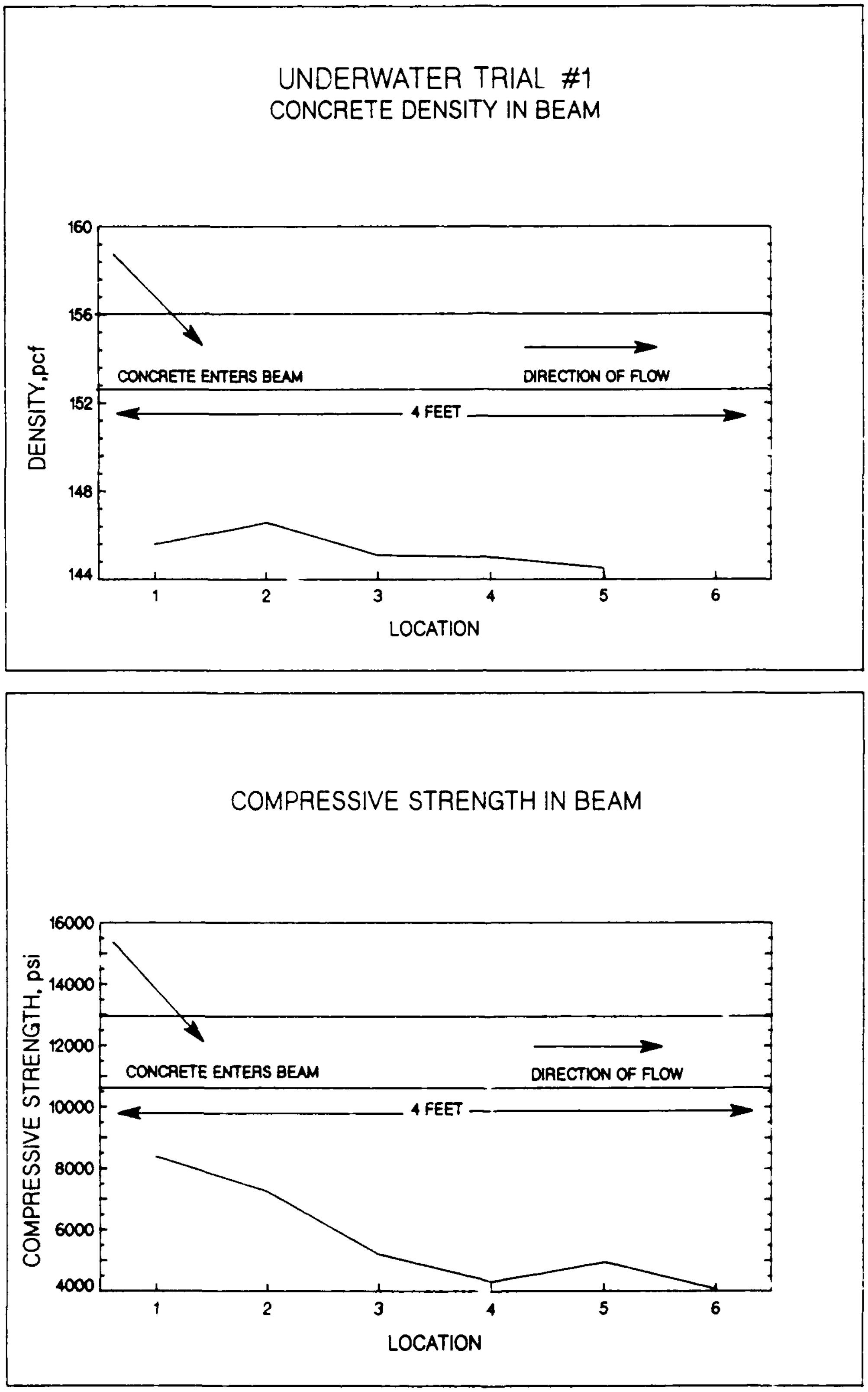


Figure 54. Concrete density and compressive strength in beam, trial 1

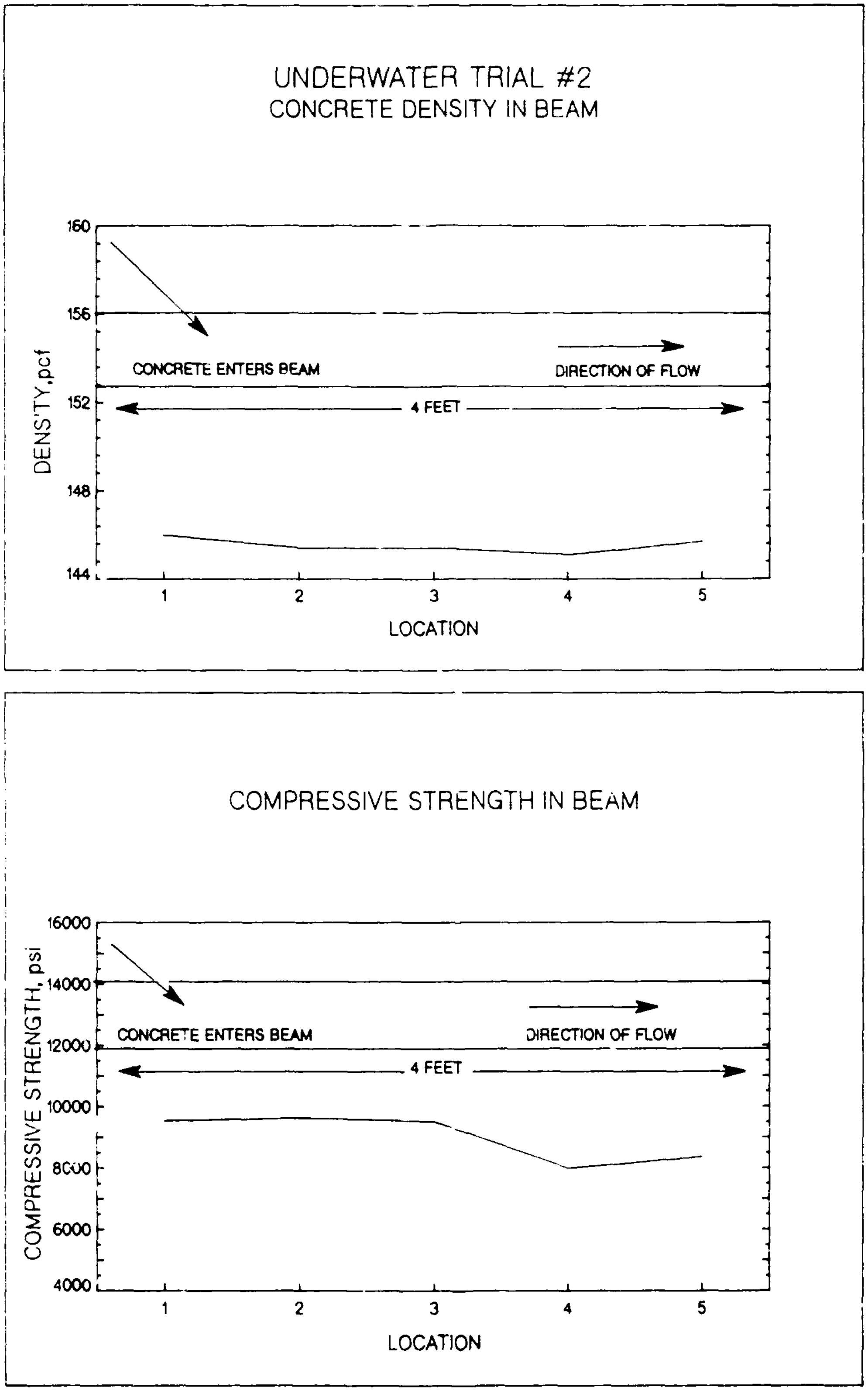


Figure 55. Concrete density and compressive strength in beam, trial 2

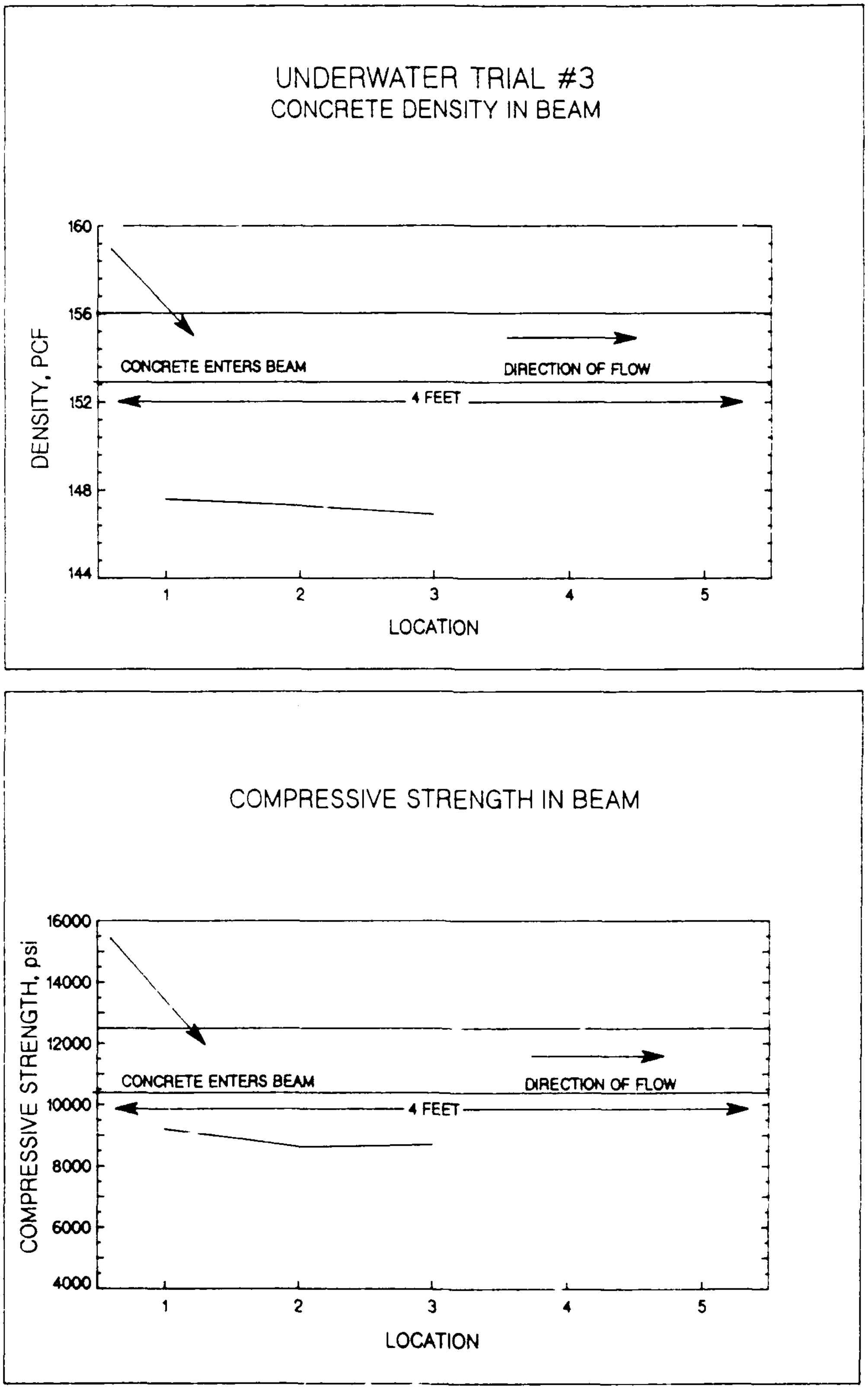
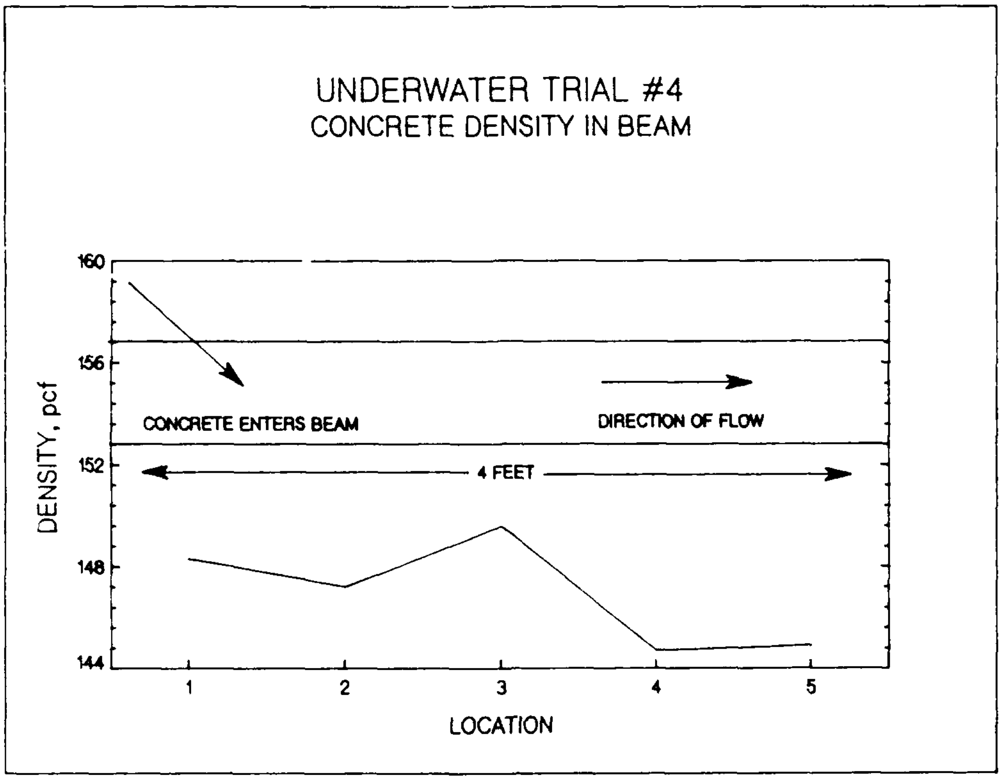


Figure 56. Concrete density and compressive strength in beam, trial 3



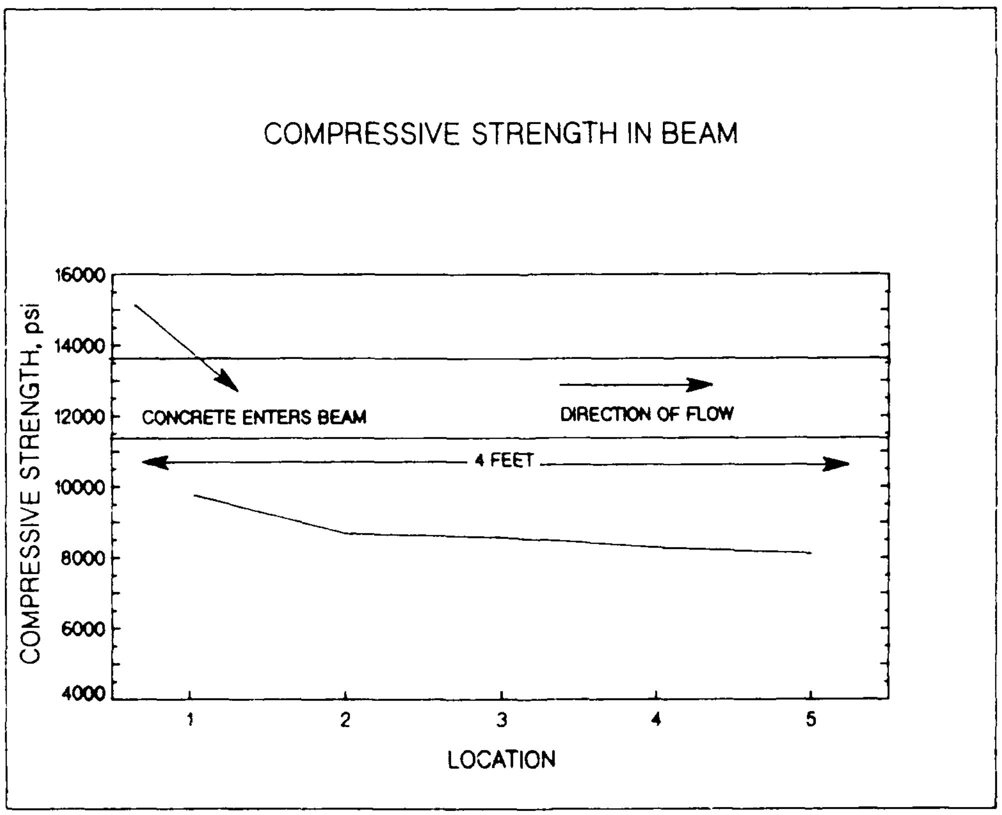
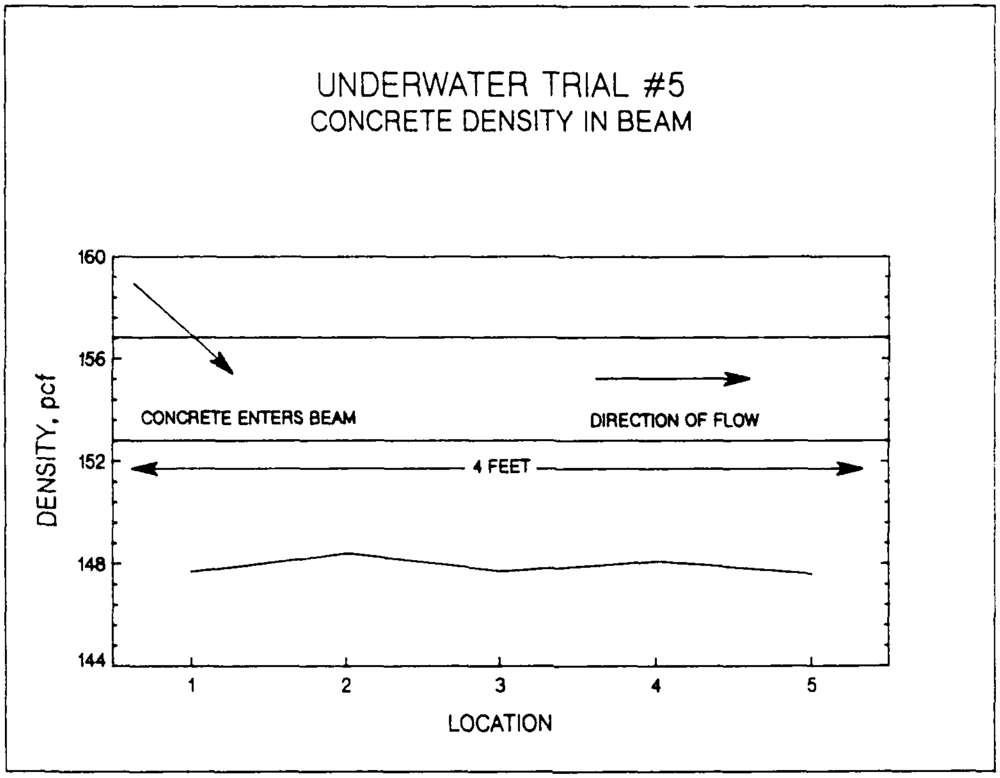


Figure 57. Concrete density and compressive strength in beam, trial 4



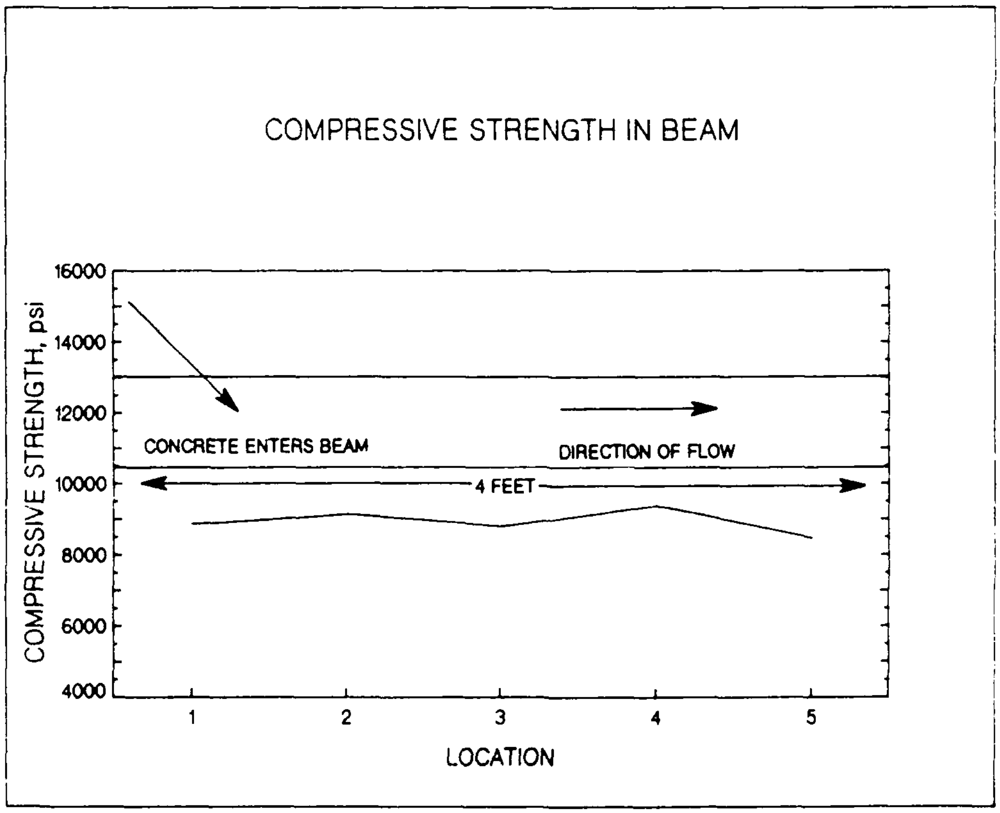


Figure 58. Concrete density and compressive strength in beam, trial 5

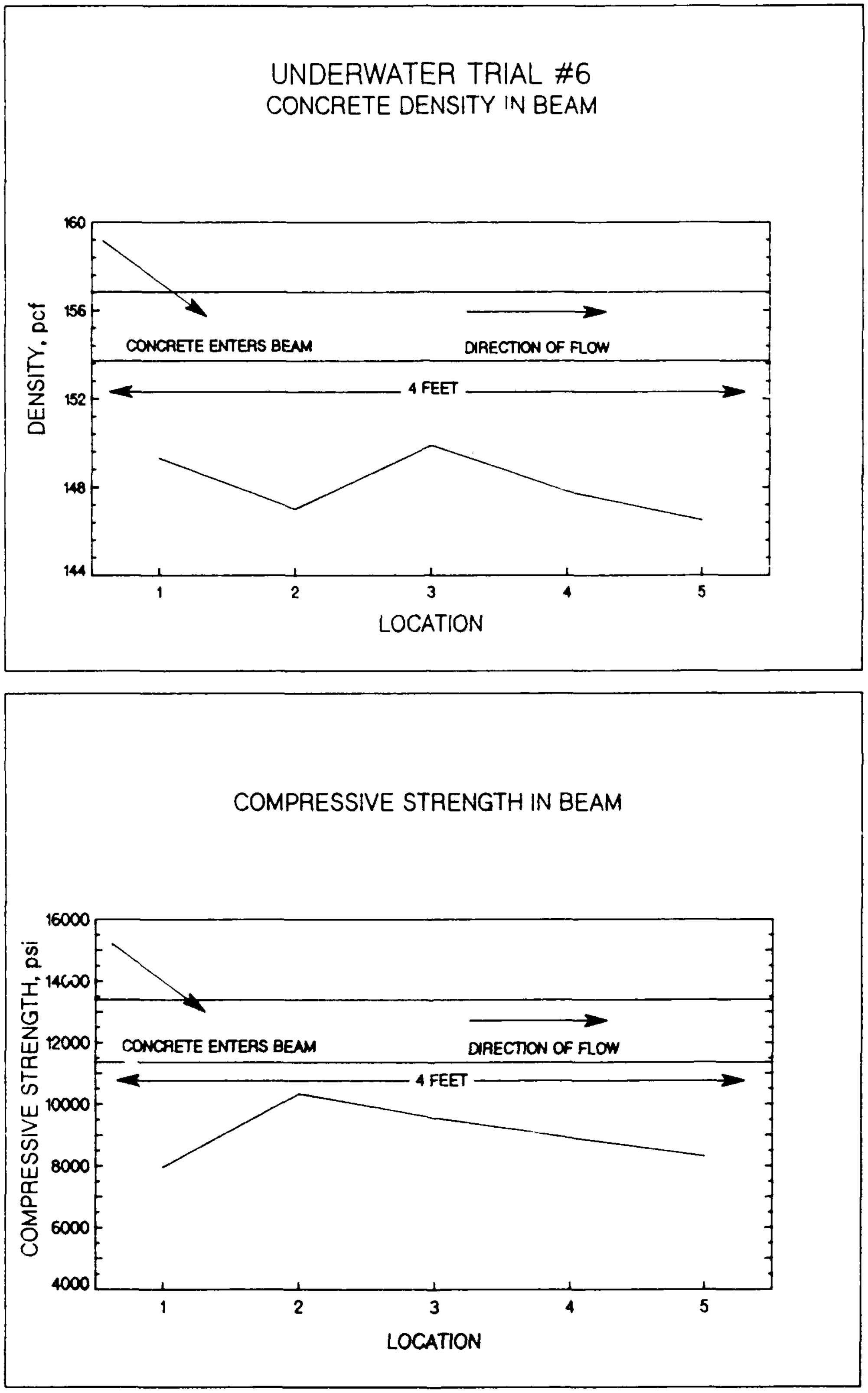


Figure 59. Concrete density and compressive strength in beam, trial 6

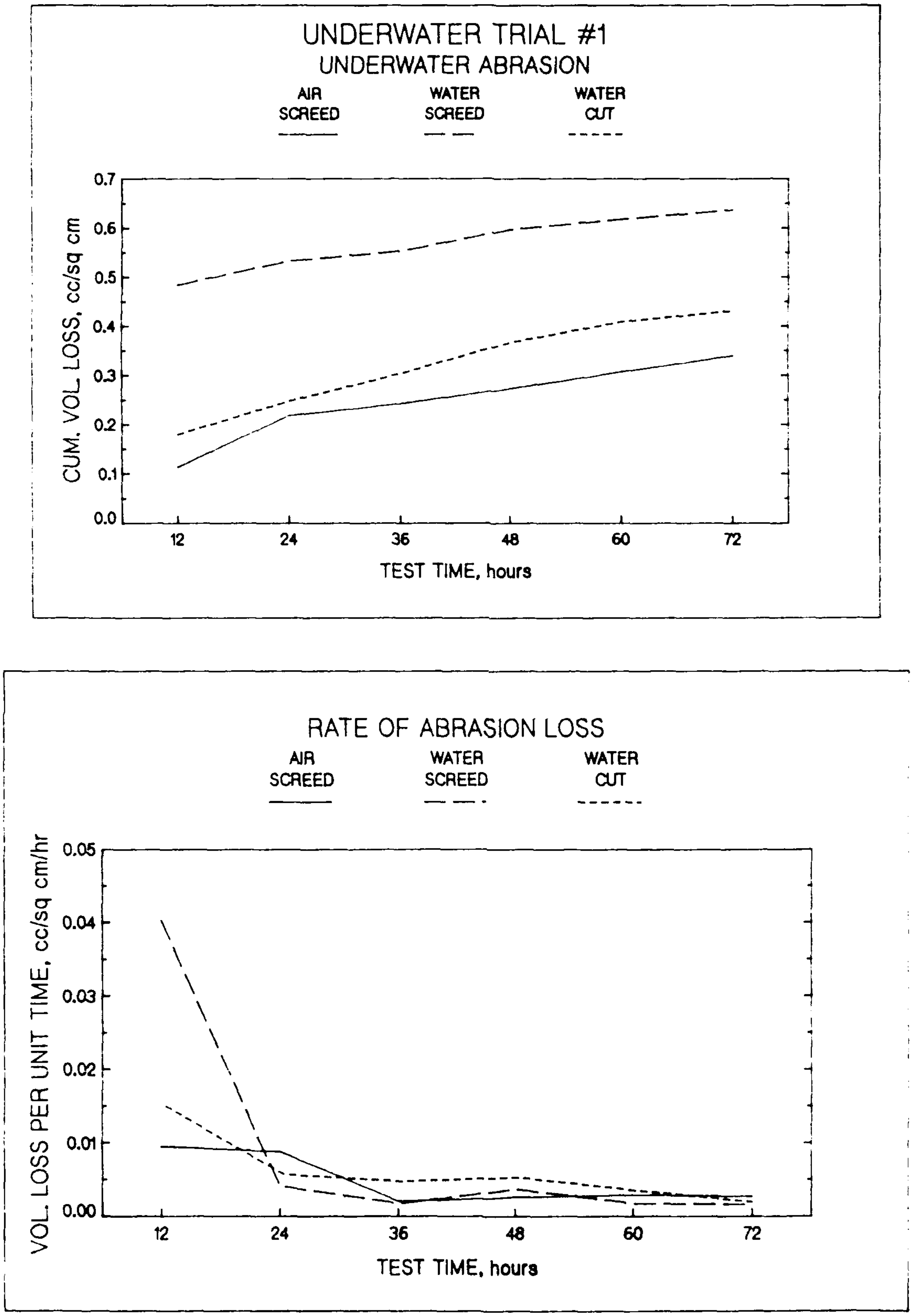
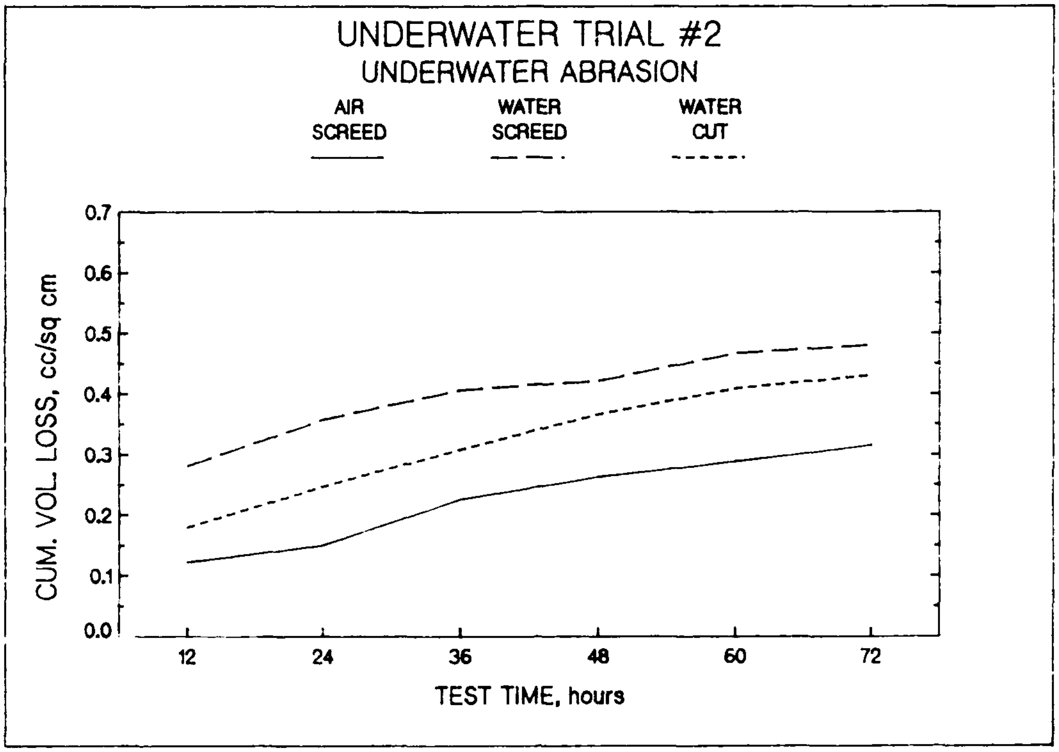


Figure 60. Underwater abrasion and rate of abrasion loss, trial 1



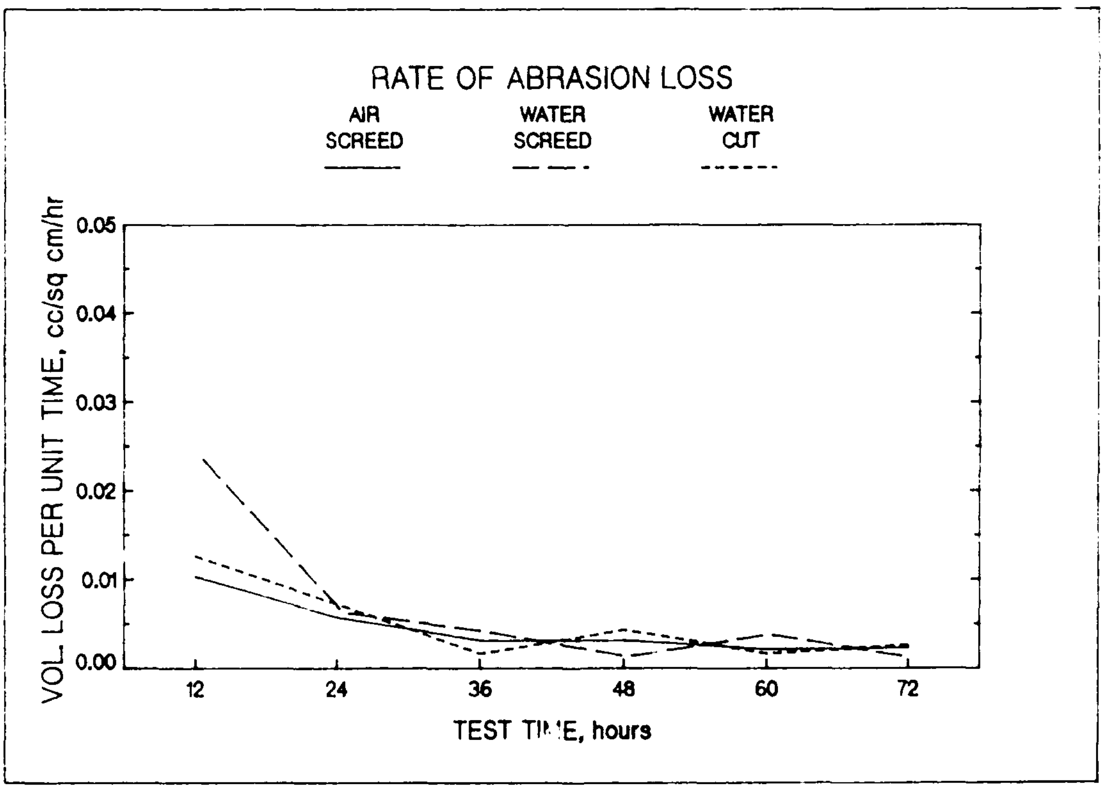


Figure 61. Underwater abrasion and rate of abrasion loss, trial 2

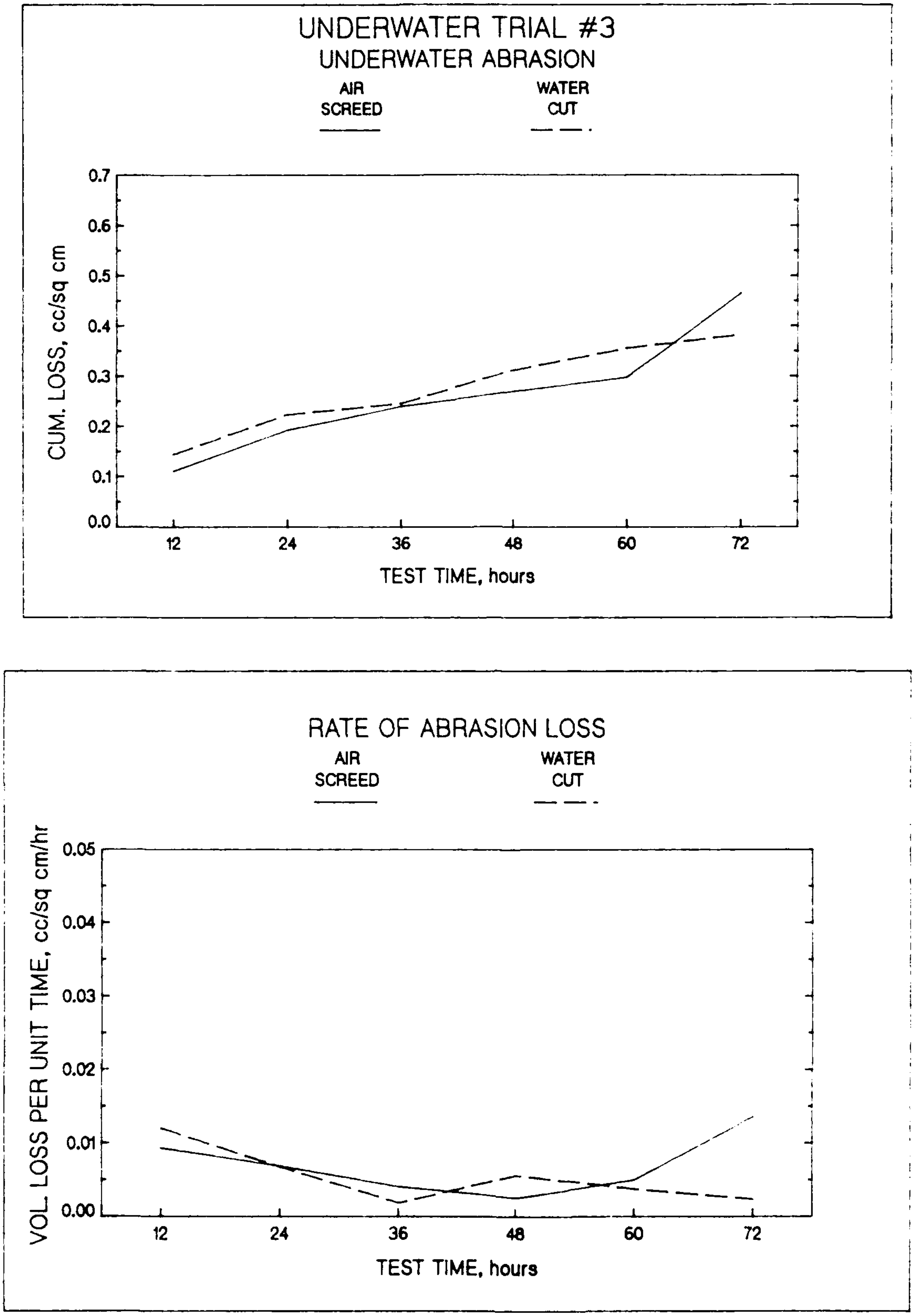


Figure 62. Underwater abrasion and rate of abrasion loss, trial 3

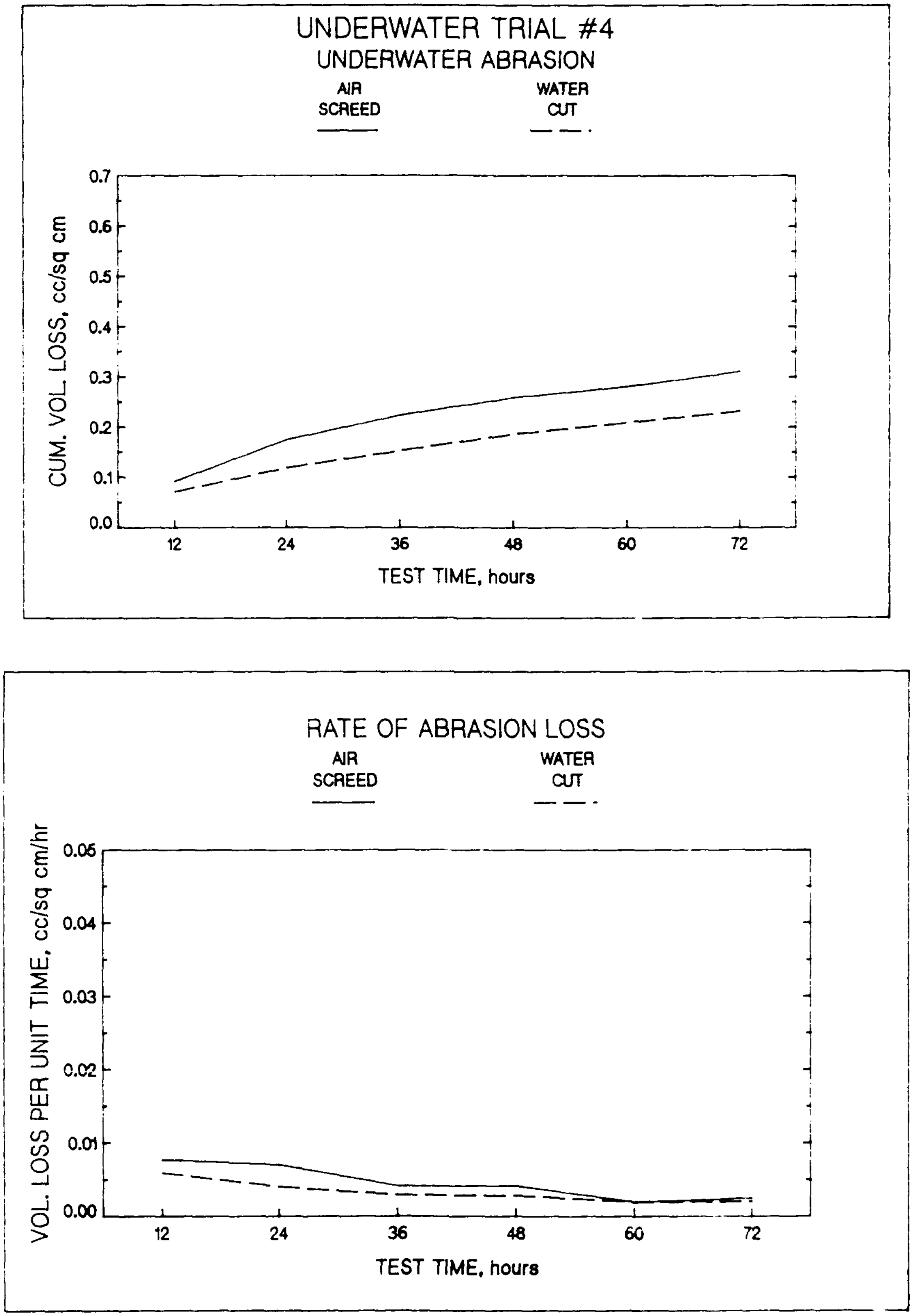
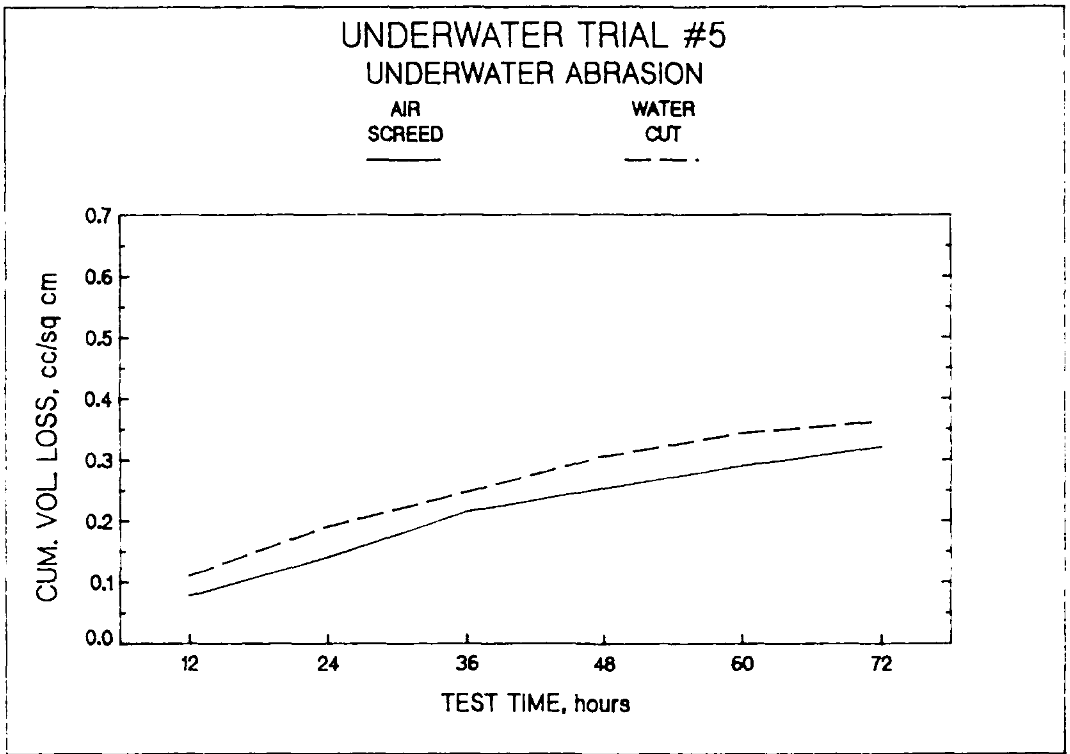


Figure 63. Underwater abrasion and rate of abrasion loss, trial 4



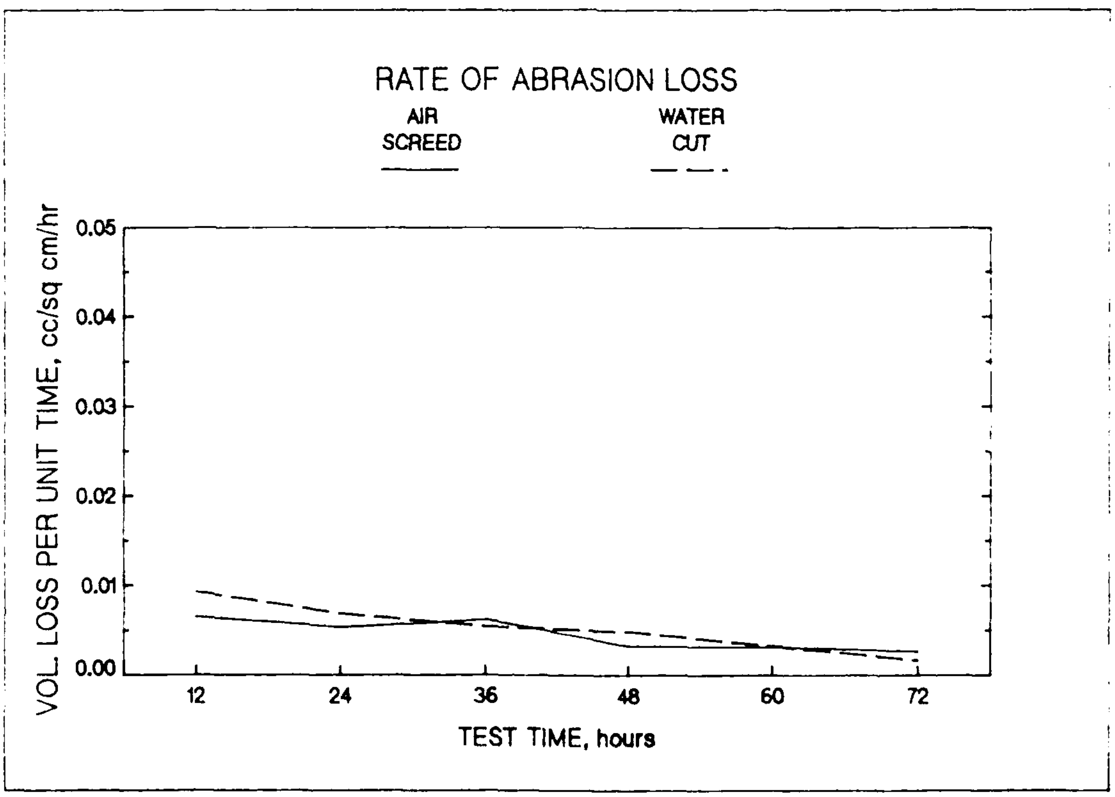
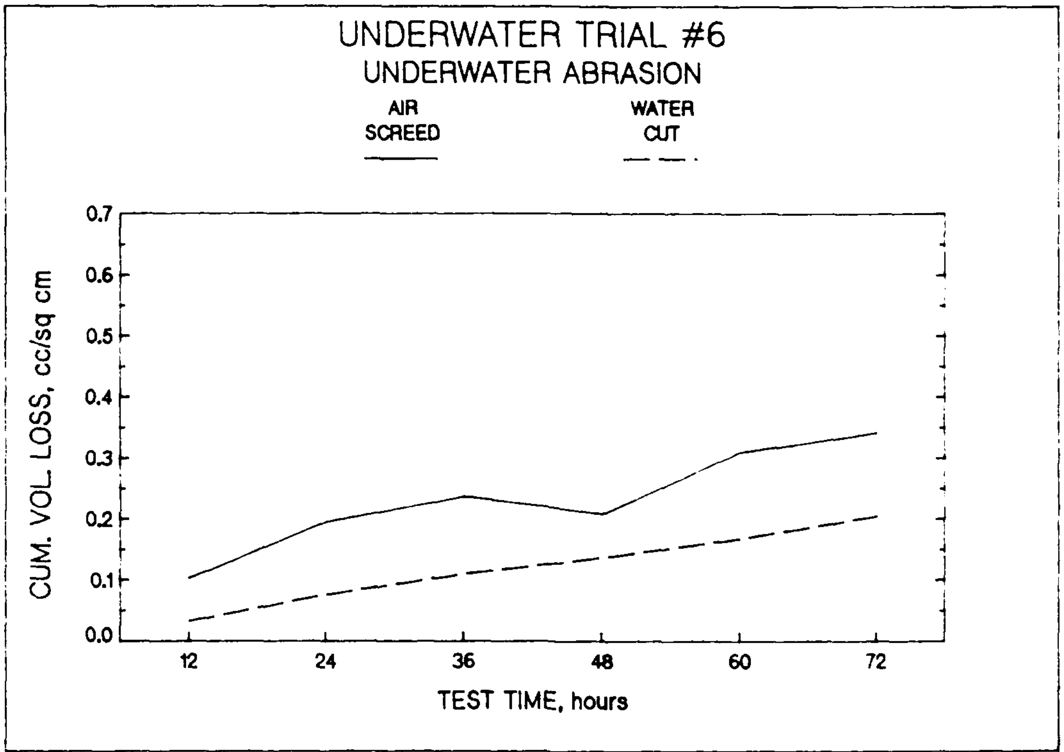


Figure 64. Underwater abrasion and rate of abrasion loss, trial 5



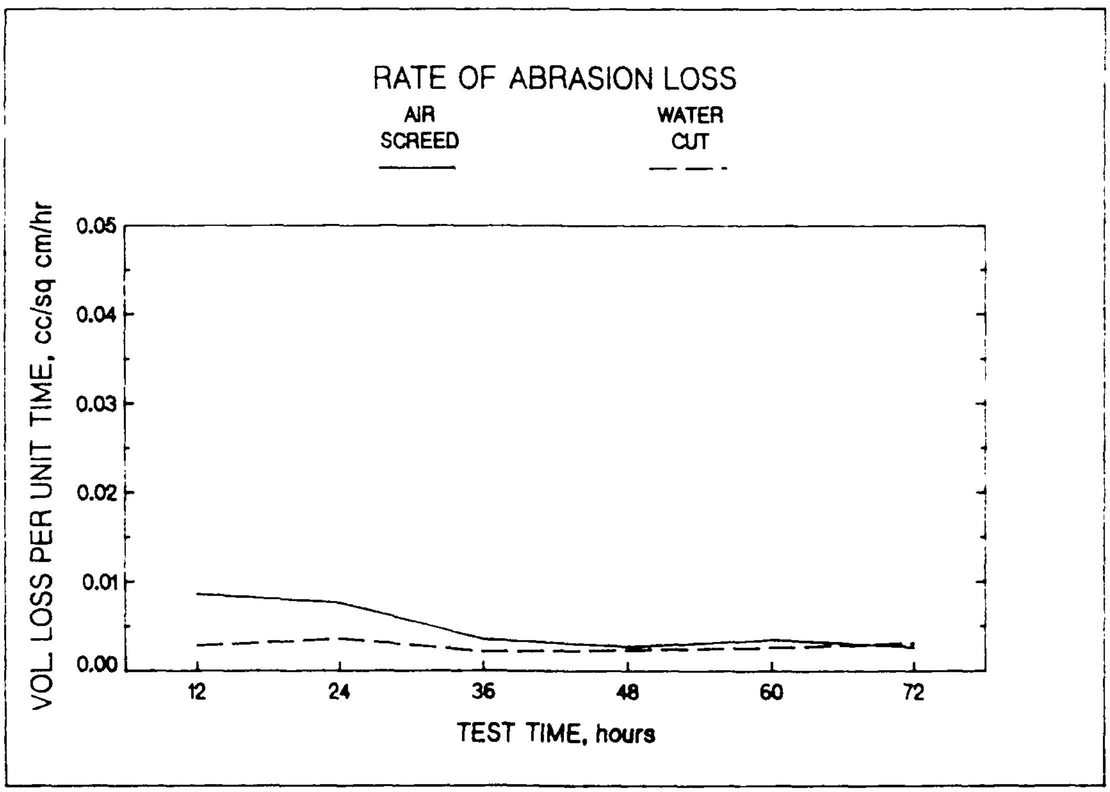
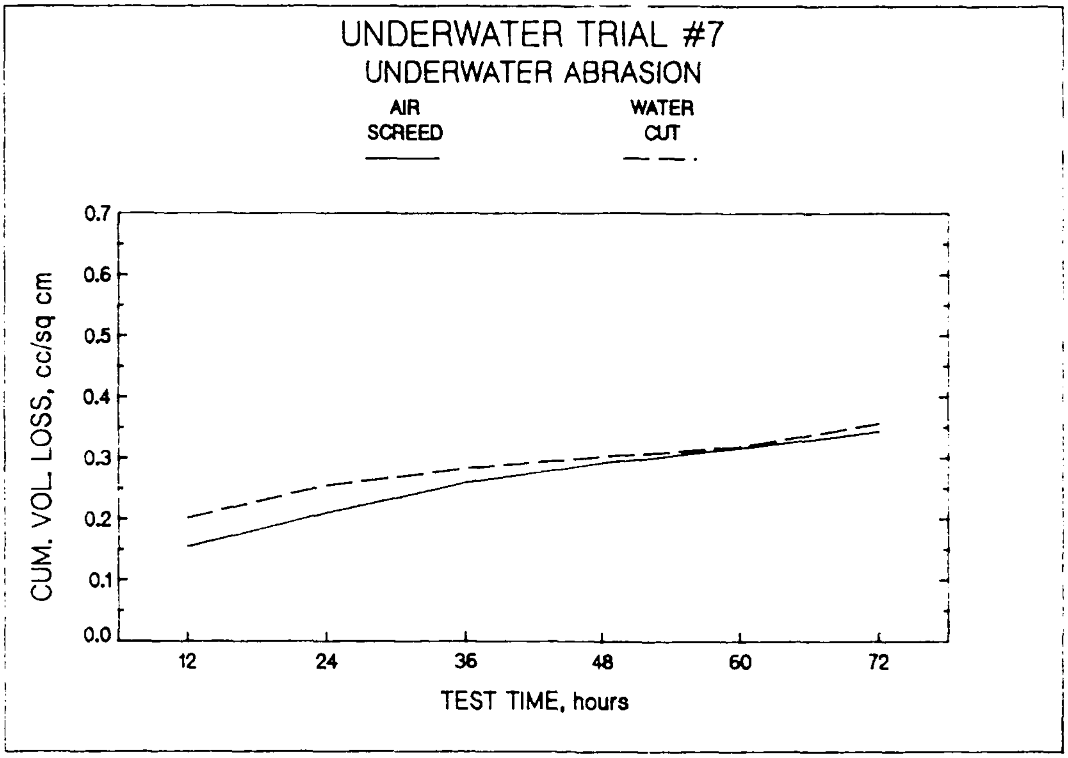


Figure 65. Underwater abrasion and rate of abrasion loss, trial 6



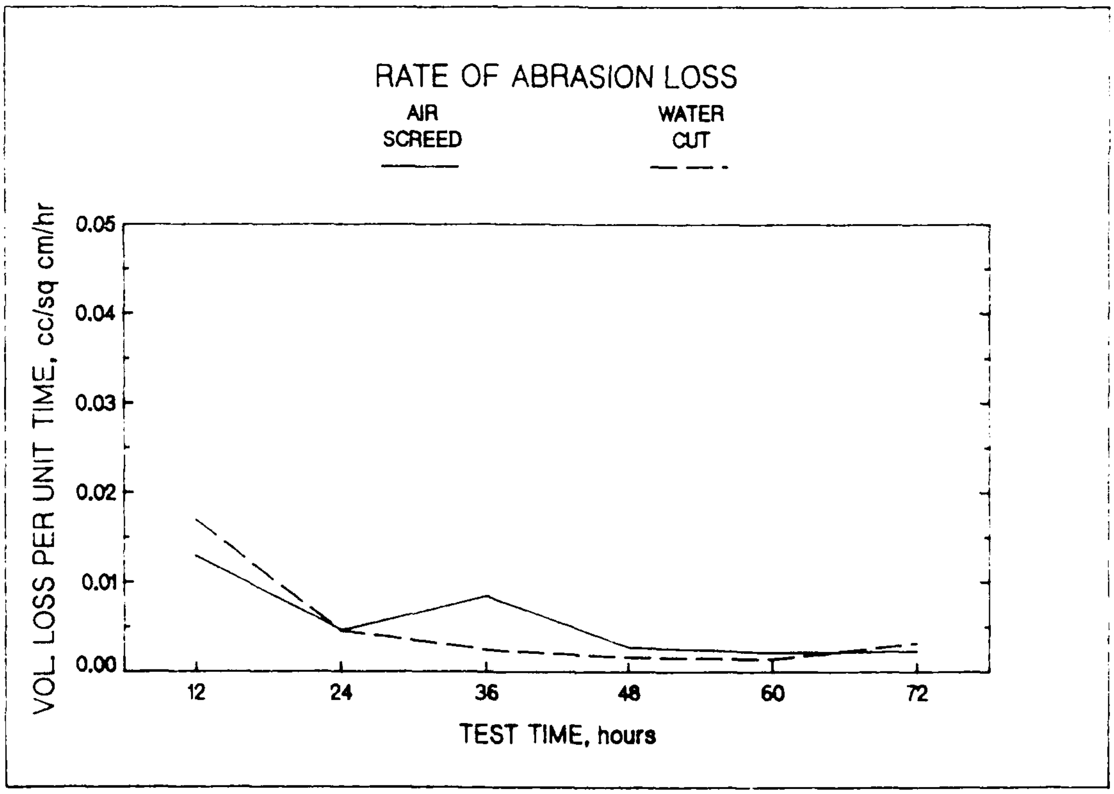
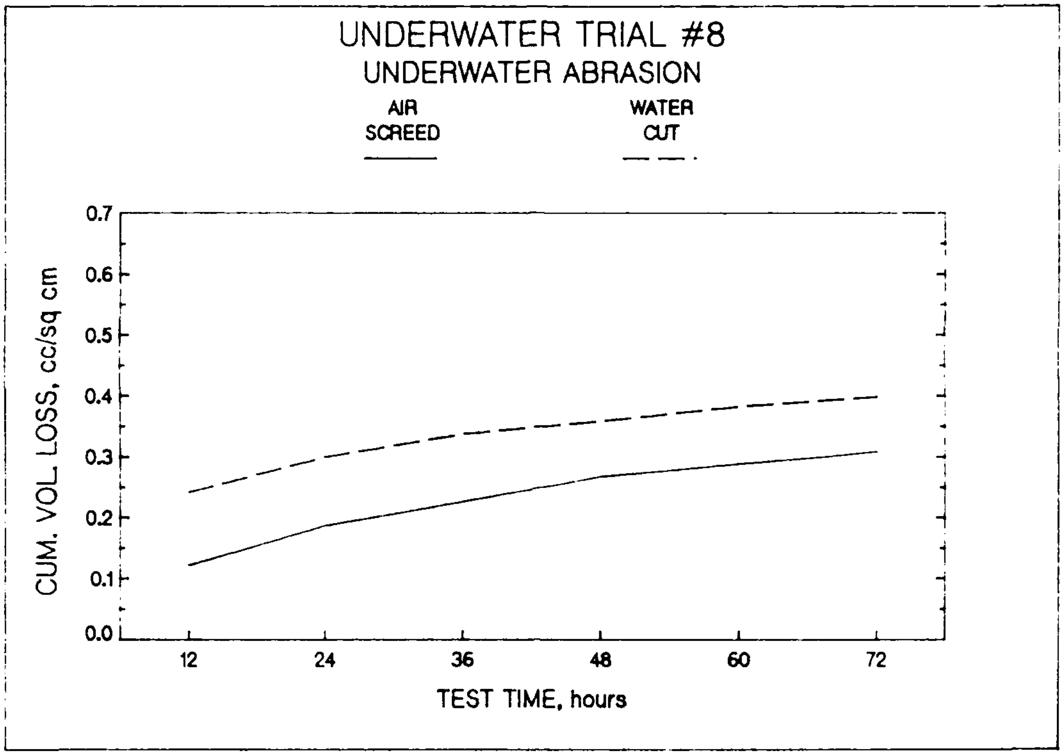


Figure 66. Underwater abrasion and rate of abrasion loss, trial 7



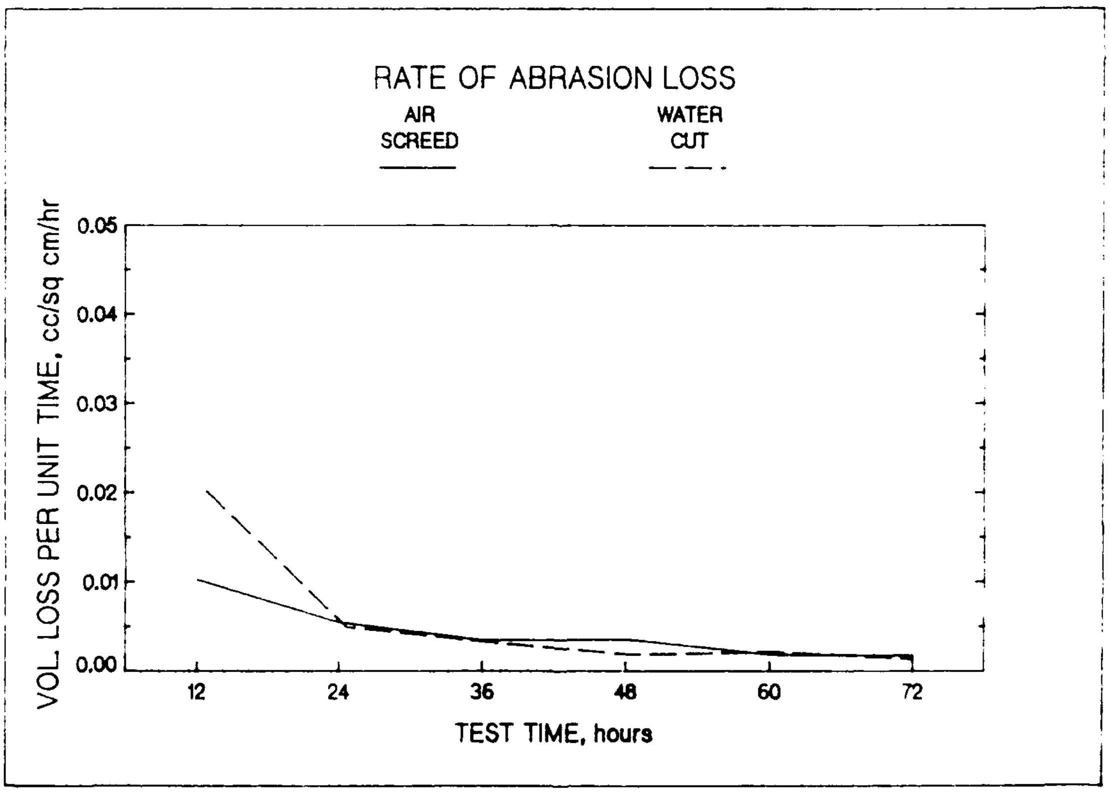
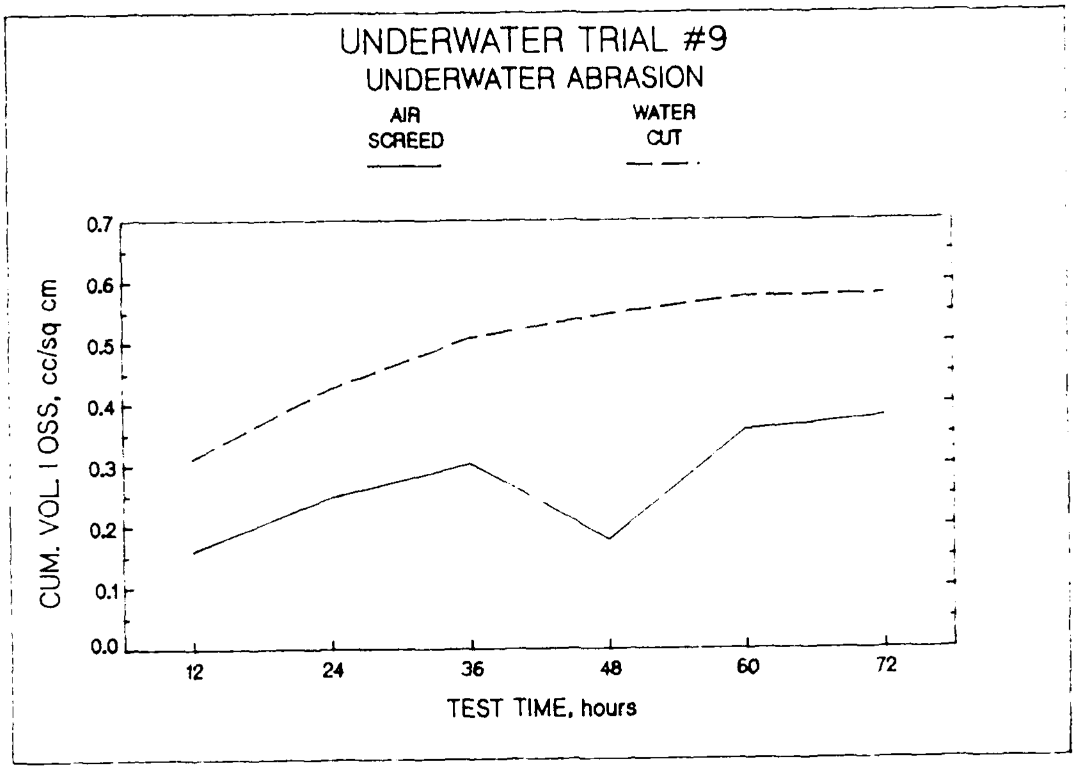


Figure 67. Underwater abrasion and rate of abrasion loss, trial 8



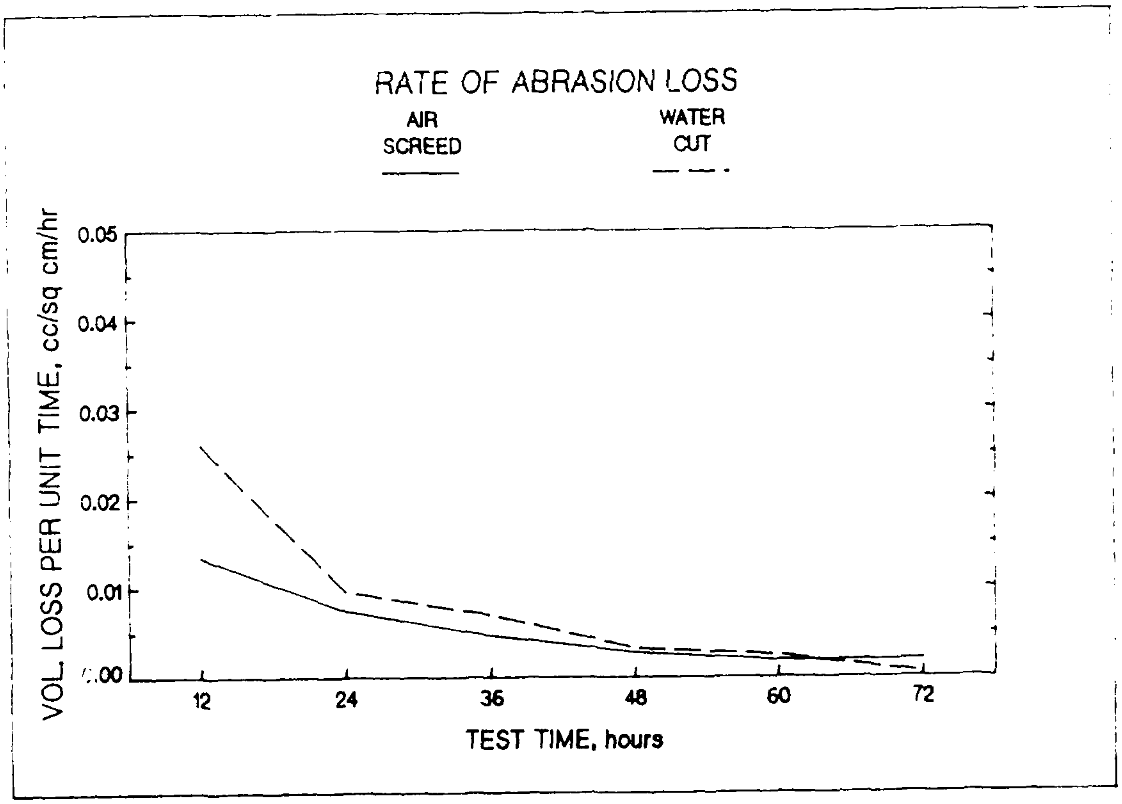
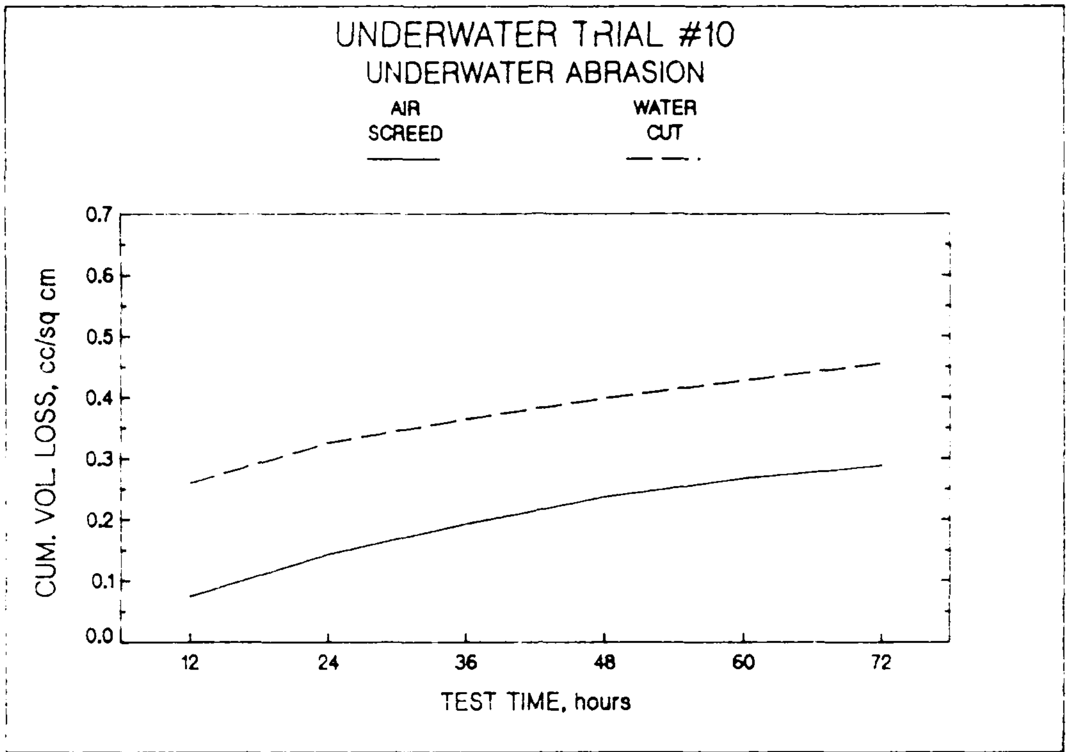


Figure 68. Underwater abrasion and rate of abrasion loss, trial 9



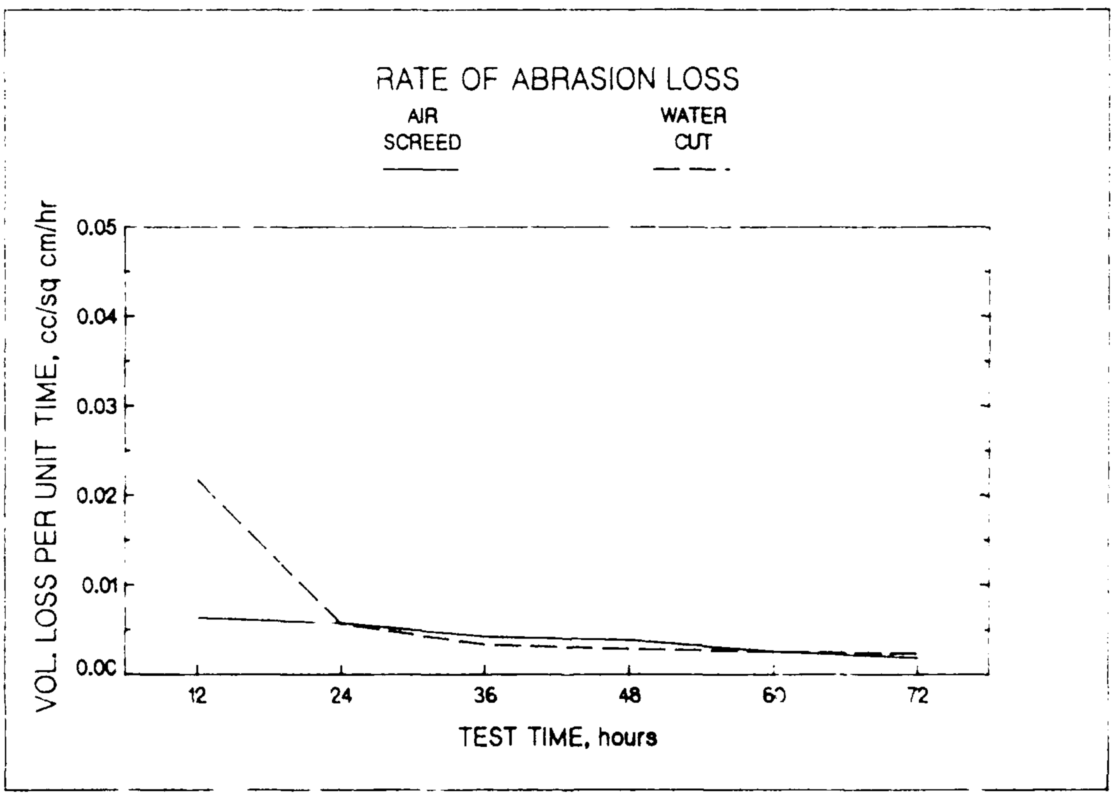
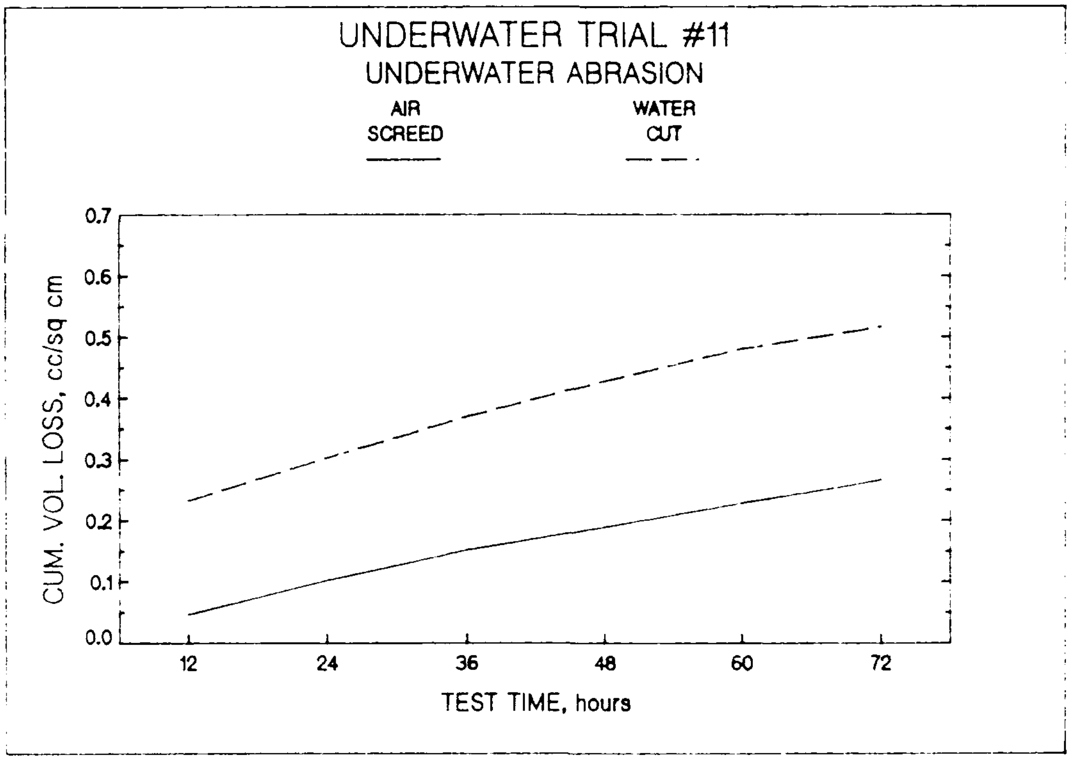


Figure 69. Underwater abrasion and rate of abrasion loss, trial 10



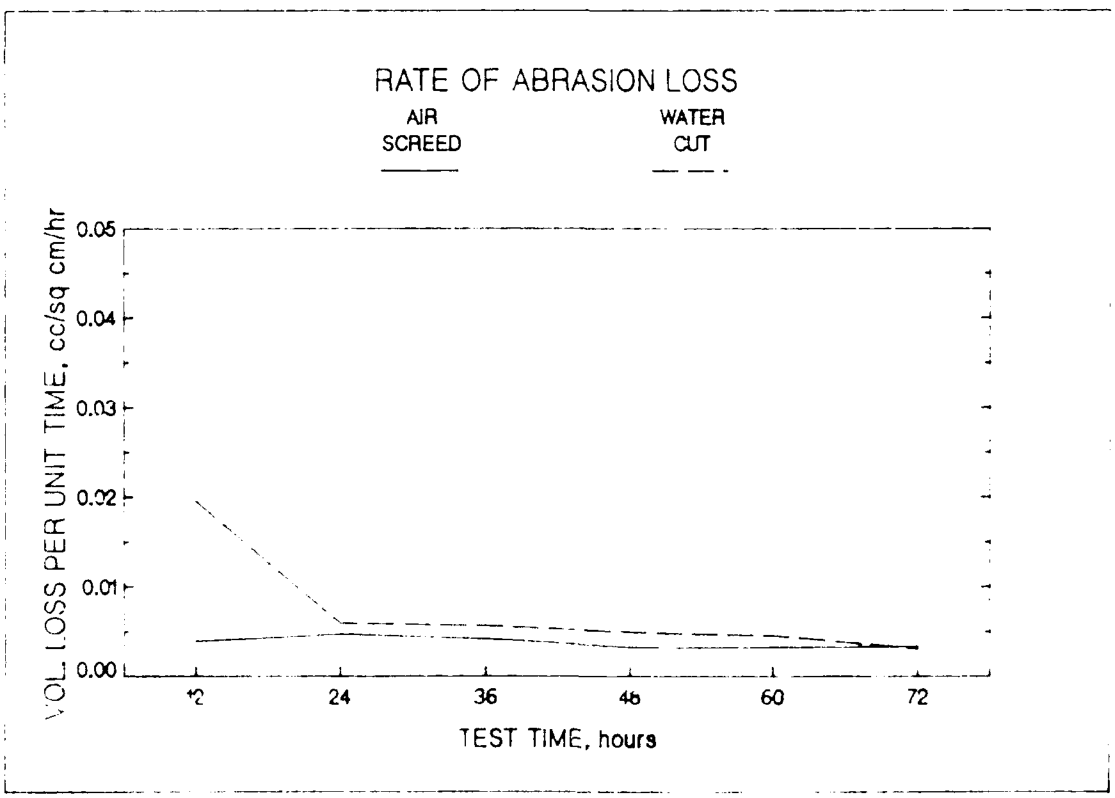


Figure 70. Underwater abrasion and rate of abrasion loss, trial 11

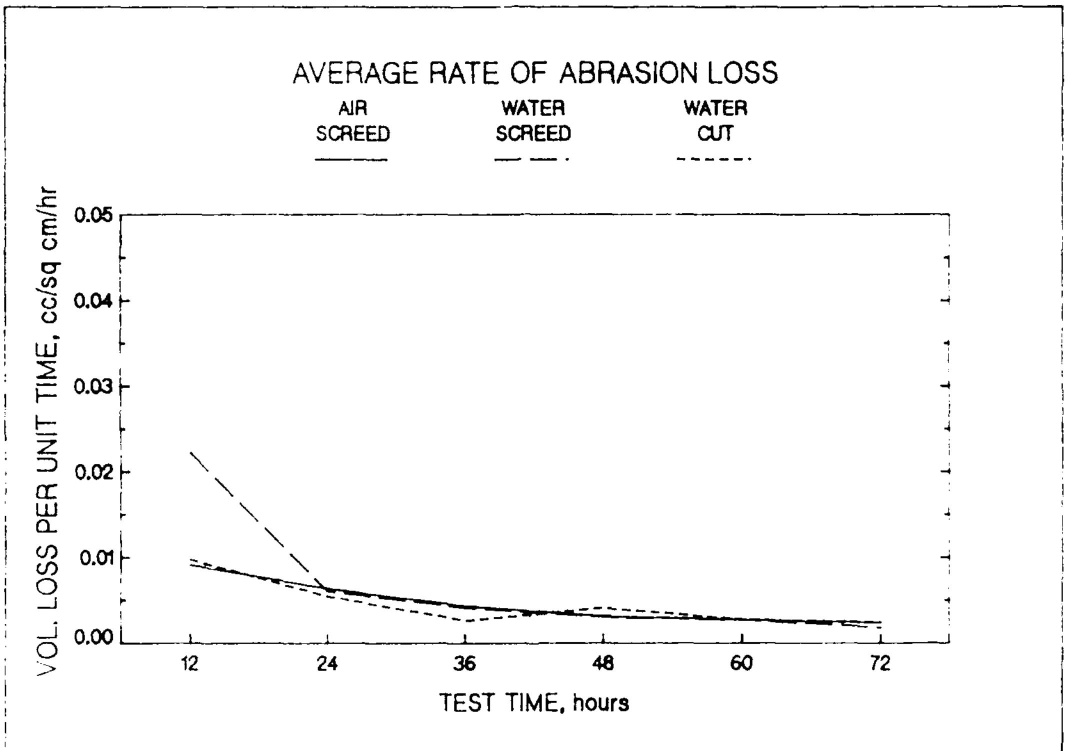


Figure 71. Average rate of abrasion loss

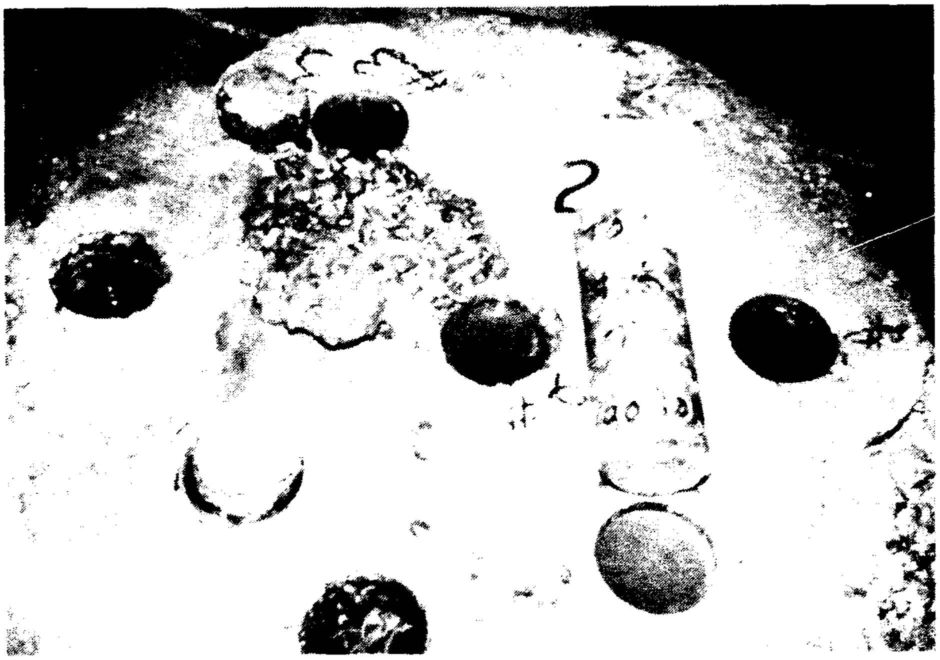


Figure 72. Cores taken from concrete placed in steel tank, trial 2

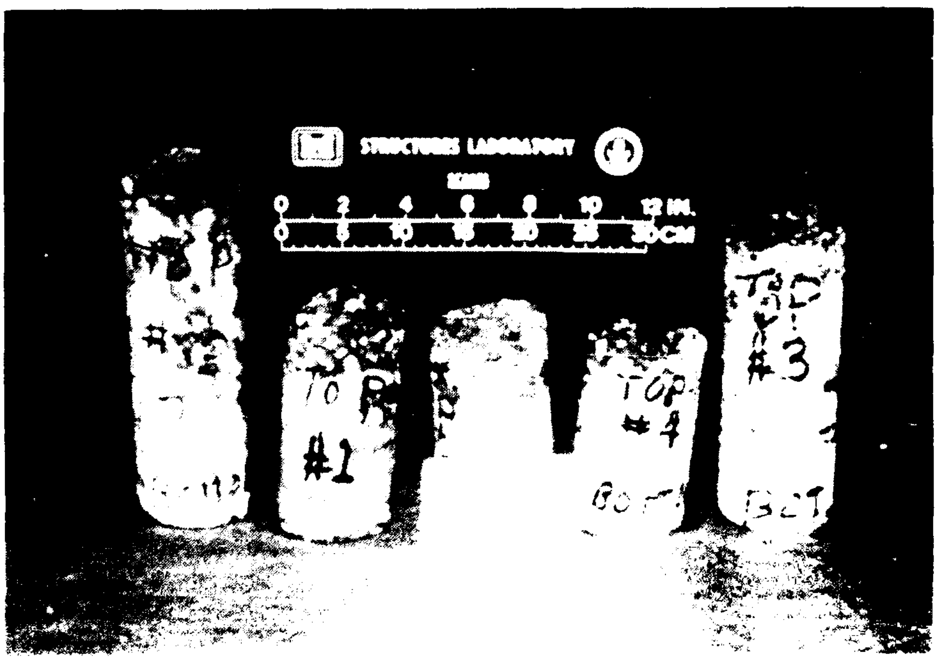


Figure 73. Cores of repair concrete bonded to existing concrete, trial 2

APPENDIX A

MEMORANDUM FOR RECORD: UNDERWATER REPAIR OF END SILL AT RED ROCK DAM, DES MOINES, IA

CEWES-SC-CG 22 Aug 88

MEMORANDUM FOR RECORD

SUBJECT: Underwater Repair of End Sill at Red Rock Dam, Des Moines, IA

1. We were contacted by Mr. Jerry Wickersham of the Rock Island District in January 1987 concerning a proposed plan to repair an eroded end sill at the Red Rock Dam located on the Des Moines River approximately 40 miles southeast of Des Moines, IA. He requested our recommendations on concrete materials and methods of placement to successfully complete an underwater repair. A plan view of the end sill detailing the eroded areas is shown in encl 1. The depth of the eroded areas was typically less than 5 ft.

2. I suggested some basic guidelines for a concrete mixture suitable for underwater placement by a pump or tremie. I also recommended use of an anti-washout admixtures (AWA), and suggested _________ and ________ as possible sources. District personnel experienced some difficulty obtaining an AWA since AWA's are still in the developmental stage by both ________ and ________. However, _________ eventually agreed to supply the product provided they could provide technical assistance in the use of the product.

3. I maintained contact with Mr. Wickersham so that we could document the repair.

4. I arrived in Des Moines on Wednesday, 10 Aug 88, and drove to the Red Rock Dam, located near Pella, IA, the following morning. I met with Mr. Ed Barleen of the Rock Island District, who had been monitoring progress of the job on a day-to-day basis. As we discussed various aspects of the job, he expressed positive comments about the capabilities of the contractor chosen to repair the end sill. The contractor, _________, of _________, had just completed drilling and grouting anchors into the bedrock where the new concrete was to be placed.

5. The concreting operation began at approximately 0845 Friday, 12 Aug. Messrs. Wickersham and Barleen were present as well as Messrs. ______ and _______ of __________. The concrete was delivered to the jobsite in ready-mix trucks containing 8-cu yd per load. The hauling time was approximately 15 min. The ready-mix trucks arrived in a timely manner; a loaded truck arrived usually within 2-3 min after the previous truck had finished unloading. The concrete pump was initially set up on the northern side of the river. The concrete was placed underwater at a depth of approximately 25 ft beginning at the middle of the end sill and working toward the north bank. Unfortunately, water in the stilling basin was so cloudy that persons viewing from above could not see the concrete being discharged into place. Water was being discharged through the dam at 300 cu ft per min during the placement. A _________ concrete pump with a 4-in. line was used to pump the concrete into place. A diver moved the end of the pumpline as necessary to completely fill the eroded areas with concrete. An attempt was made to keep the end of the

pump line embedded in the mass of newly discharged concrete at all times. Approximately 40 cu yd of concrete was placed in the northern half of the end sill. This section was completed at 1000. At that time, the concrete pump was moved to the southern side of the river and set up to place concrete into this half of the end sill. The concreting operations began once again at 1130. This time the ready-mix trucks stacked up waiting to unload, typically waiting 15-20 min after arriving at the jobsite. However, workability of the concrete appeared to be unaffected by the delay. Approximately 60 cu yd of concrete was placed in the southern half of the end sill. This section was completed at 1400. The diver inspected the entire placement before coming to the surface and reported that all eroded areas were completely filled and the first concrete placed was beginning to harden.

6. The concrete mixture appeared to have characteristics appropriate for a successful underwater placement. The slump was near 9 in. The effects of the AWA were apparent; even though the concrete had a high slump, the mixture was cohesive. The contractor initially had reservations about the pumpability and flowability of the concrete; however, the doubts were removed soon after the operation began. The concrete pumped very well and, according to the diver, was very mobile. He reported that the concrete did not self-level immediately after placement, but did self-level within a few minutes after placement. This is consistent with our laboratory trials with concretes containing AWA's. The diver also reported that on a few occasions the discharge end of the pump line kicked out of the mass of newly placed concrete. Even then, the concrete remained cohesive and exhibited very little loss of fines. The concrete mixture proportions for 1 cu yd are as follows:

Cement (Type I)	700 lb
Fine aggregate (natural)	1,299 lb
Coarse aggregate (3/4-in. crushed limestone)	1,594 lb
Water	275 lb
WRA	42 oz
AEA	2 oz
AWA	5 lb

I do not consider the air entrainment necessary for this particular job. In fact, our laboratory work suggests that air contents in excess of 3-4 percent can reduce the cohesiveness of the concrete containing AWA, making it more susceptible to washout. The air content of this mixture was near 8 percent, but did not appear to cause any problems because the contractor made every effort to keep the discharge end of the pump line embedded in the concrete mass at all times.

7. In summary, I would consider the concrete placement very successful. The contractor was conscientious and attempted to follow proper procedures for underwater placement of concrete. The concrete had a suitable workability and the properties appeared to be consistent from load to load. I believe the AWA

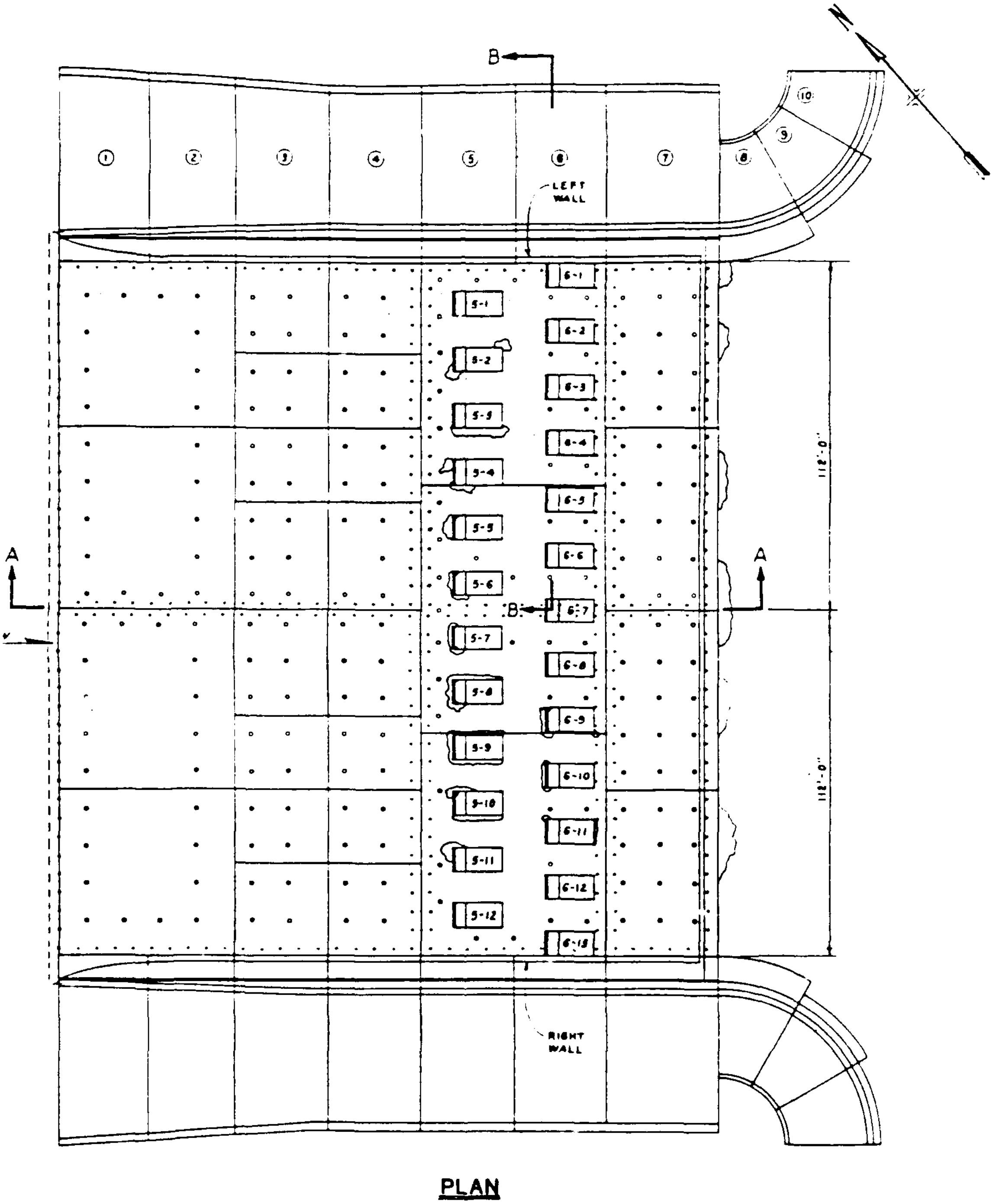
was beneficial to the operation, even though this repair could have possibly been successful without use of an AWA. The use of an AWA increases the chances of a successful concrete placement because it is difficult for a diver to ensure that the discharge end of a pump line always remains embedded in the mass of newly placed concrete, especially when the repair area is relatively shallow and spread over a large area. The AWA will prevent a loss of fines and formation of rock pockets if the pump line accidentally becomes dislodged from the mass of newly placed concrete. The AWA is relatively expensive ($5 per lb) and therefore should not be used indiscriminately. However, when the job requirement is such that will require frequent movement of the pump line, tremie pipe, etc., the benefits probably outweigh the costs.

8. I made a video tape of all the concreting operations available on the surface. I have the tape in my office.

Encl

BILLY D. NEELEY
Civil Engineer
Concrete Technology Division

CF:
Jerry Wickersham
Jim McDonald
Bill McCleese



End sill plan view

(Blocks 5-1 through 5-12 and 6-1 through 6-13 indicate eroded areas)

Encl 1